The Scottish Office
Agriculture and Fisheries
Department

Persistent Organochlorine Contaminants in Fish and Shellfish from Scottish Waters

A G Kelly
and
D Campbell

Scottish Fisheries
Research Report
Number 54 1994
ISSN 0308 8022

LIBRARY

JAN 1 0 1995

National Marine Fisheries Service
2570 Dole Street
Honolulu, Hawaii

Previous Scottish Fisheries Research Reports

Series Editor: J.W. Smith

1975 No.1 The Aberdeen Single-Anchor Mooring.
By R. Payne, 7pp.

No.2 The Aberdeen Shallow Water Current Meter Mooring.
By R. Payne, 13pp.

1976 No.3 The Bridger Version of the Gulf III High Speed Plankton Sampler.
By J.A. Adams, 42pp.

No.4 Some Parasites of Plaice *Pleuronectes platessa* L. in Three Different Farm Environments.
By K. MacKenzie, A.H. McVicar and I.F. Waddell, 14pp.

No.5 Simulation of Vertical Structure in a Planktonic Ecosystem.
By J.H. Steele and E.W. Henderson, 27pp.

No.6 The Intertidal Fauna of Sandy Beaches - a Survey of the Scottish Coast.
By A. Eleftheriou and A.D. McIntyre, 61pp.

1977 No.7 A Net Drag Formula for Pelagic Nets.
By Aenea J. Reid, 12pp.

No.8 The Aberdeen Sedimentation Trap and its Moorings.
By R. Payne and J.M. Davies, 11pp.

No.9 A Preliminary Model of Shear Diffusion and Plankton Populations.
By G.T.Evans, J.H. Steele and G.E.B. Kullenberg, 19pp.

No.10 Diving Observations on the Efficiency of Dredges used in the Scottish Fishery for the Scallop *Pecten maximus* (L).
By C.J. Chapman, James Mason and J.A.M. Kinnear, 16pp.

1978 No.11 Comparative Fishing for Flatfish using a Beam Trawl fitted with Electric Ticklers.
By P.A.M. Stewart, 10pp.

No.12 The Value of Direct Observation Techniques by Divers in Fishing Gear Research.
By J. Main and G.I. Sangster, 15pp.

1979 No.13 The Occurrence of Plerocercoids of *Diphyllobothrium* spp. in Wild and Cultured Salmonids from the Loch Awe Area.
By R. Wootten and John W. Smith, 8pp.

No.14 A Study of Bottom Trawling Gear on both Sand and Hard Ground.
By J. Main and G.I. Sangster, 15pp.

No.15 The Coastal Movements of Returning Atlantic Salmon, *Salmo salar* L.
A.D. Hawkins, G.G. Urquhart and W.M. Shearer, 14pp.

No.16 Hydrodynamic Characteristics of Trawl Warps.
By D.N. MacLennan, 10pp.

No.17 Some Parasites and Diseases of Blue Whiting, *Micromesistius poutassou* (Risso), to the North and West of Scotland and at the Faroe Islands.
By K. MacKenzie, 14pp.

1980 No.18 Changes in the Respiration and Blood Circulation of Cod, *Gadus morhua* L., induced by Exposure to Pollutants.
By A.D.F. Johnstone and A.D. Hawkins, 18pp.

1981 No.19 Survey of Trace Elements in Fish and Shellfish landed at Scottish Ports 1975 - 76.
By I.M. Davies, 28pp.

No.20 A Study of the Sand Clouds Produced by Trawl Boards and their Possible Effect on Fish Capture.
By J. Main and G.I. Sangster, 20pp.

No.21 Orientation and Energetic Efficiency in the Offshore Movements of Returning Atlantic Salmon and *Salmo salar* L.
By G.W. Smith, A.D. Hawkins, G.G. Urquhart and W.M. Shearer, 22pp.

No.22 The Theory of Solid Spheres as Sonar Calibration Targets.
By D.N. MacLennan, 17pp.

No.23 A Study of the Fish Capture Process in a Bottom Trawl by Direct Observations from a Towed Underwater Vehicle.
By J. Main and G.I. Sangster, 23pp.

1982 No.24 A Study of Separating Fish from *Nephrops norvegicus* L. in a Bottom Trawl.
By J. Main and G.I. Sangster, 8pp.

No.25 Target Strength Measurements on Metal Spheres.
By D.N. MacLennan, 11pp.

No.26 A Study of a Multi-Level Bottom Trawl for Species Separation Using Direct Observation Techniques.
By J. Main and G.I. Sangster, 17pp.

1983 No.27 Fish Reactions to Trawl Gear - a Study Comparing Light and Heavy Ground Gear.
By J. Main and G.I. Sangster, 17pp.

No.28 Guidelines for the Use of Biological Material in First Order Pollution Assessment and Trend Monitoring.
By G. Topping, 28pp.

No.29 TUV II - a Towed Wet Submersible for Use in Fishing Gear Research.
By J. Main and G.I. Sangster, 19pp.

The Scottish Office
Agriculture and Fisheries
Department

Persistent Organochlorine Contaminants in Fish and Shellfish from Scottish Waters

A G Kelly
and
D Campbell

Scottish Fisheries
Research Report
Number 54 1994
ISSN 0308 8022

Contents

	Page
Introduction	3
Sampling Strategy	4
Methods	6
Quality Control	7
Results	7
Discussion	18
Spatial Distribution	18
Chlorobiphenyls	20
DDT Compounds	20
Dieldrin	20
Chlordane Compounds	20
Hexachlorobenzene	21
Lindane	21
Small-Scale Studies	21
Conclusions	24
References	25
Appendix : *Characteristics of Organochlorine Determinands*	26

Digitized by the Internet Archive
in 2025

https://archive.org/details/scottish-fisheries-research-reports_1994_54

Persistent Organochlorine Contaminants in Fish and Shellfish from Scottish Waters

A G Kelly and D Campbell
Marine Laboratory, Aberdeen

Introduction

Most of the fishing industry in the United Kingdom is based on Scottish waters. In 1991, some 432 thousand tonnes of fish and shellfish worth 267 million pounds were landed by UK boats at Scottish ports. This constitutes 72% of the total UK catch by weight and 63% by value. Of particular importance are landings of pelagic fish such as herring and mackerel, 91% of which were landed at Scottish ports (SOAFD, 1993). The Marine Laboratory directs a substantial effort towards monitoring the abundance, behaviour and health of these fish stocks. Part of this work involves assessment of the biological and chemical quality of the marine environment and the effects of changes in quality on fish stocks. Monitoring of the concentration of contaminants in the marine environment is also undertaken to supply data to national and international baseline studies such as the joint monitoring programme of the Oslo and Paris Commissions, the North Sea Task Force Monitoring Plan and the United Kingdom National Monitoring Plan. Of particular significance is the concentration of organochlorine pollutants in fish and shellfish. Many of these pollutants are toxic and persistent, and being hydrophobic in nature, tend to accumulate in fatty tissues (eg Lee, 1992). Comprehensive data are currently lacking on the abundance of such materials in fish from Scottish waters. Accordingly, during 1991 and 1992 representative samples of the important commercially exploited fish and shellfish species were obtained from the major fishing areas. These data have been combined with existing data from 1989 and 1990 to provide a comprehensive survey of current baseline concentrations of organochlorine contaminants in liver and muscle of fish and shellfish from Scottish waters.

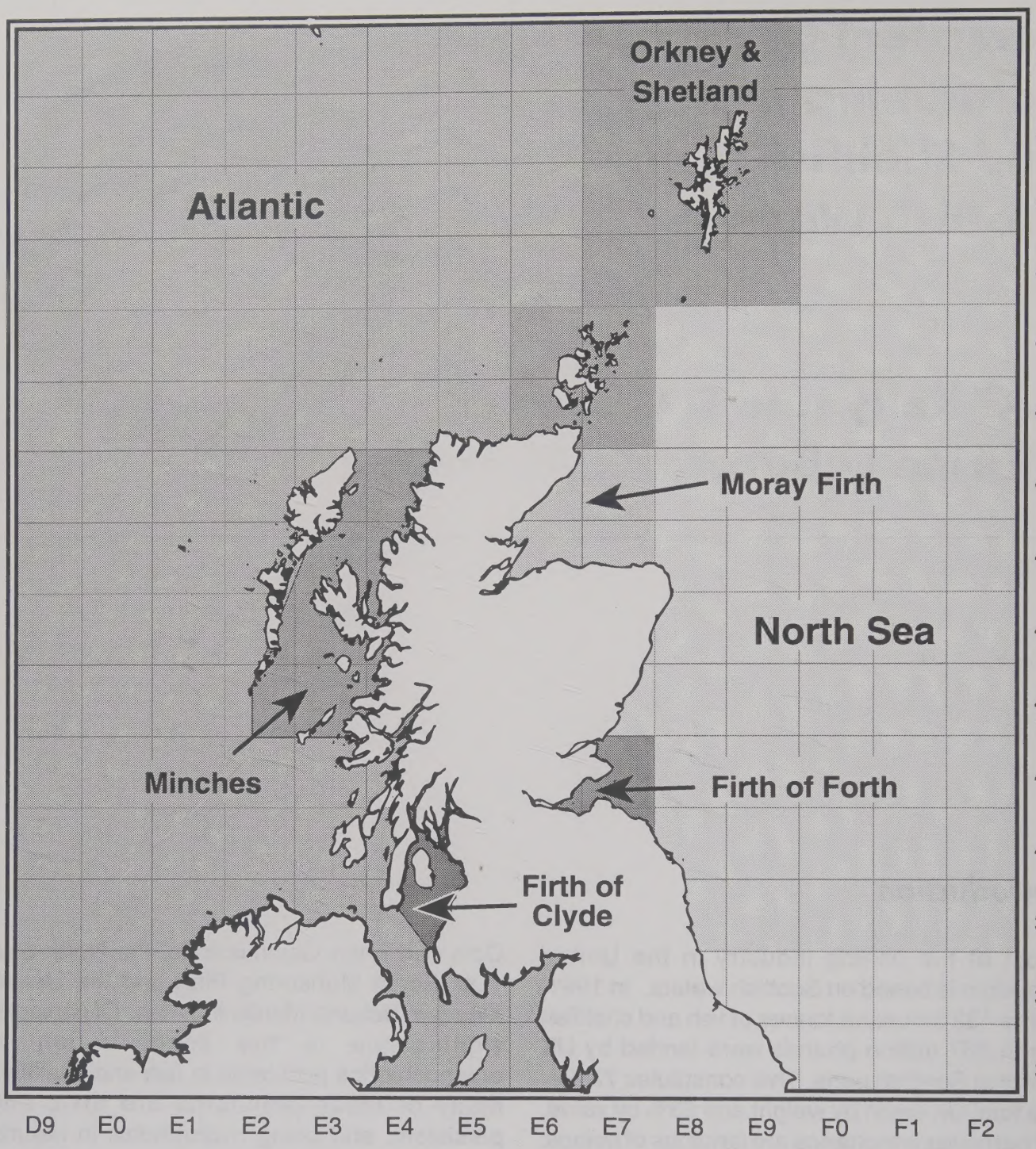

Figure 1. Sampling areas mentioned in the text.

Sampling Strategy

Sampling areas (Fig. 1) were selected on the basis of either high reported landings or the potential for elevated concentrations, eg the Firth of Clyde and the area around the former Piper Alpha oil production platform subject to a release of chlorobiphenyls in 1988 (Wells *et al.*, 1989). In the Firth of Clyde, samples were taken at seven sites ranging from Garroch Head in the north, to a site outside the Firth, namely, in the North Channel in the south. The Piper Alpha area was sampled at four locations ranging from 10 to 60 km from the site of the wreck. The samples collected covered both the recommended monitoring species (JMG, 1990)

and other commercially important species (Table I).

Target sampling criteria are listed in Table II. These are in accord with those laid down by the Joint Monitoring Group (JMG) of the Oslo and Paris Commissions for the determination of spatial distribution purpose "C" (JMG, 1990).

These criteria were not achieved for every sample. For the majority of samples, only one analysis was performed, but for some a pooling approach was taken, with several pools of five fish being individually analysed. This approach permits a statistical assessment of the variability of the data (eg Kelly *et al.*, 1994). In such cases, the standard deviation of the results is given.

Table I : Summary of species sampled in each area

		Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Cod	*Gadus morhua*	■	■	■	■		■	
Haddock	*Melanogrammus aeglefinus*	■		■	■	■	■	■
Whiting	*Merlangius merlangus*	■	■	■	■		■	■
Saithe	*Pollachius virens*	■						
Hake	*Merluccius merluccius*	■						
Plaice	*Pleuronectes platessa*	■		■		■	■	■
Dab	*Limanda limanda*		■	■	■		■	
Lemon sole	*Microstomus kitt*			■			■	
Megrim	*Lepidorhombus whiffiagonis*						■	
Witch	*Glyptocephalus cynoglossus*				■			
Herring	*Clupea harengus*	■	■	■	■	■	■	■
Mackerel	*Scomber scombrus*							■
Norway lobster	*Nephrops norvegicus*	■		■	■		■	
Shrimp	*Pandalus borealis*				■			
Scallop	*Pecten maximus*			■			■	
Edible crab	*Cancer pagurus*		■	■				

Table II : Target sampling criteria

Species	Spawning time	Sampling time	Length range (cm)	No of individuals	Tissue
Cod	Feb – Apr	Early winter	30 – 45	25	Liver
Haddock	Feb – Jun	Early winter	30 – 45	25	Liver
Whiting	Jan – Jul	Early winter	20 – 35	25	Liver
Hake	Mar – Jul	Early winter	25 – 40	25	Liver
Saithe	Jan – Apr	Early winter	25 – 40	25	Liver
Ling	Mar – Jul	Early winter		25	Liver
Plaice	Jan – Mar	Early winter	25 – 40	25	Liver
Dab	Feb – Jun	Early winter	20 – 30	25	Liver
Flounder	Feb – Jul	Early winter	15—35	25	Liver
Halibut	Nov – Mar	Aug-Sep		25	Liver
Sole	Jan – Jun	Early winter	25 – 40	25	Liver
Herring	Variable*		20 – 35	25	Muscle
Mackerel	Apr – Jul	Spring	20 – 35	25	Muscle
Nephrops	Sep	Summer	15 – 20	25	Muscle
Scallops	Autumn	Summer		50	Muscle
Edible crab	Autumn	Summer		25	Muscle
Pandalus	–	Summer		50	Muscle
Witch	May – Jul	Spring	25 – 40	25	Liver

*There are distinct herring populations which may spawn at different times. In most areas, herring spawn in the autumn. Exceptions are the Clyde which supports both spring and autumn spawning stocks, and the Forth which may have a local spring spawning stock.

Methods

Fish and shellfish were taken by the research vessels FRV "Clupea" and FRV "Scotia" and dissected on board ship. Livers and muscle fillets were removed, wrapped in aluminium foil and frozen in liquid nitrogen, prior to storage at -20°C.

Individual samples were dried by mixing with anhydrous sodium sulphate followed by soxhlet extraction with dichloromethane. After lipid determination, clean-up and group separation was by alumina/silica chromatography (Wells *et al.*, 1985). Instrumental analysis was performed by capillary gas chromatography with an electron capture detector. Instrumental conditions are listed in Table III. Data were quantified by a 5-level stepped calibration using the Minichrom data system. Organochlorine compounds determined are listed in the Appendix.

The identity of major quantified peaks was confirmed by negative-ion chemical ionisation mass spectrometry using a Hewlett-Packard 5989A mass spectrometer equipped with a 50 m by 0.22 mm CPSIL8 column, with methane reagent gas at 1.5 torr, a source temperature of 150°C, and electron energy of 230eV.

Table III : Chromatographic conditions for the analysis of organochlorine contaminants

	CBs and HCB	Pesticides
Instrument	Varian 3500 with automated on-column injection	Varian 3500 with automated on-column injection
Column	CP-SIL8 50 m x 0.22 i.d., 0.2 µm phase thickness	CP-SIL19 50 m x 0.22 i.d., 0.2 µm phase thickness
Carrier gas	Hydrogen, 35 cm s^{-1}	Hydrogen, 40 cm s^{-1}
Oven programme	80°C, 1 min, 3°C min^{-1} to 270°C, hold 10 min	80°C, 1 min, 3°C min^{-1} to 270°C, hold 10 min
Injection	0.5 µl on-column	0.5 µl on-column
Injector programme	120°C, 1 min, 300°C min^{-1} to 280°C, hold 60 min	120°C, 1 min, 300°C min^{-1} to 280°C, hold 60 min
Detector	ECD, 320°C	ECD, 320°C

Quality Control

The methods used in this study have been validated through participation in national and international intercalibration exercises. In addition, the quality of the data was monitored by an ongoing laboratory quality control scheme. The between-batch coefficient of variance for analysis of a laboratory reference fish oil utilised for control of the method was 15% for chlorobiphenyls and 25% for pesticides. The accuracy of the method was assessed by regular analyses of reference materials certified for chlorobiphenyls by the Bureau of Community Research.

Results

The concentrations of organochlorine compounds in fish and shellfish expressed on a wet weight basis are tabulated in Tables IV to X. A summary chlorobiphenyl measure was calculated as an Arochlor 1254 equivalent as detailed in the Appendix. The data are summarised as the concentration range of all determinands in cod, haddock, whiting, plaice, dab, herring and *Nephrops* in Tables XI to XVII.

Data on contaminant levels in biota can be considered in terms of the range of values presently found in the marine environment. The JMG have developed a set of arbitrary descriptive guidelines for several toxic metals and for chlorobiphenyls (Table XVIII) derived from observed values. In terms of these guidelines, the mean concentrations of chlorobiphenyls found in this study fall into the following categories:

For fish liver:

upper level	no areas
medium level	Clyde cod and saithe; Forth dab
lower level	all other areas/species

For fish muscle:

upper level	no areas
medium level	Clyde cod, hake and saithe; Moray Firth dab
lower level	all other areas/species

For crustaceans:

upper level	no areas
medium level	Clyde *Nephrops*
lower level	all other areas/species

Table XIX lists the maximum and associated mean values for organochlorine contaminants in fish from Scottish waters. For comparison, guidelines for the assessment of possible hazard to human health in the United Kingdom and the strictest European guidelines (JMG, 1992) are included.

Table IV
Firth of Forth (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Cod	56°10N 02°20W	08/06/91	14/1	21-54	29.0	11.6	14.8	41.1	65.7	187.5	128.5	73.0	1,305.5	38.7	<2	57.2	25.9	109.9	25.6	21.3	168.0
Cod	56°06N 02°40W	08/11/91	16/1	29-59	49.0	12.5	5.6	18.8	28.8	78.2	56.3	33.4	583.9	33.0	4.3	30.0	43.6	60.8	21.2	14.6	100.7
Whiting	56°06N 02°40W	08/11/91	26/1	27-41	39.0	9.9	4.2	9.9	10.8	25.5	20.7	9.3	225.5	20.2	3.7	15.6	21.9	28.6	20.6	9.1	62.3
Dab	56°10N 02°20W	01/01/91	15/3	19-29	20.6	7.9	11.5	40.8	36.7	116.3	86.2	33.1	831.0	17.6	6.0	97.8	211.0	158.7	33.3	48.3	413.5
sd								(8.54)	(7.34)	(14.06)	(15.07)	(4.53)		(8.59)	(2.10)	(56.60)	(18.76)	(50.04)	(10.01)	(22.24)	
Dab	56°10N 02°20W	03/92	60/60	20-24	11.7	7.4	7.8	11.1	9.8	24.4	19.5	5.9	200.0	<2	3.2	<2	106.3	28.1	18.9	22.4	60.3
Fish Muscle																					
Cod	56°06N 02°40W	08/11/91	16/1	29-59	0.48	0.31	0.11	0.21	0.25	0.50	0.38	0.26	5.05	0.20	0.06	0.13	0.20	0.30	0.09	0.05	0.44
Whiting	56°06N 02°40W	08/11/91	26/1	27-41	0.59	0.69	0.48	0.60	0.37	0.39	0.35	0.12	7.50	0.33	0.21	0.04	0.21	0.26	0.12	0.06	0.55
Herring	56°10N 02°20W	01/01/91	25/5	21-26	4.60	2.30	<0.8	1.13	1.20	2.29	1.89	0.85	24.15	1.74	1.60	<0.8	2.88	2.25	<0.8	<0.8	2.25
sd						(0.78)				(0.47)	(0.41)			(0.57)	(0.53)		(0.78)	(0.61)			
Shellfish																					
Crab	41E7	24/06/92	6/1	15-20	0.30	0.28	0.04	0.06	0.30	0.65	0.46	0.18	4.95	1.66	0.12	0.21	0.64	0.41	0.01	0.03	0.51

Table V
Moray Firth (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Cod	44E7	05/11/91	19/1	30-61	51.0	12.8	8.1	11.6	16.6	41.3	29.7	9.9	324.9	8.6	3.1	32.5	27.7	44.6	4.8	11.4	60.7
Whiting	44E7	05/11/91	31/1	26-34	44.6	12.1	6.4	14.8	21.3	58.0	42.2	23.3	445.2	13.9	3.2	21.8	13.3	45.2	5.7	10.0	64.5
Haddock	44E7	05/11/91	25/1	27-43	51.4	12.6	7.0	7.8	10.4	26.9	19.2	6.1	225.2	6.9	3.1	21.7	17.6	20.8	4.3	6.5	31.6
Dab	44E7	05/11/91	24/1	22-29	40.8	10.8	5.4	7.7	8.6	17.2	14.1	3.7	168.8	5.8	1.9	14.9	15.5	14.9	2.9	5.6	25.6
Sole	44E7	05/11/91	22/1	17-32	23.6	6.1	4.0	4.5	5.4	11.7	9.7	2.4	109.7	4.7	1.4	30.7	53.4	17.3	2.3	8.1	36.8
Plaice	44E7	05/11/91	25/1	28-36	28.6	7.2	4.1	5.9	7.2	12.5	11.4	3.2	128.9	4.2	<1	9.1	13.1	13.9	2.3	3.2	21.1
Fish Muscle																					
Cod	44E7	05/11/91	19/1	33-71	0.38	0.35	0.17	0.23	0.18	0.24	0.21	0.04	3.55	0.06	0.05	0.19	0.12	0.20	0.04	0.03	0.30
Whiting	44E7	05/1191	31/1	26-34	0.57	0.49	0.12	0.11	0.11	0.17	0.16	0.04	3.00	0.06	0.13	0.06	0.14	0.18	0.05	0.08	0.31
Haddock	44E7	05/11/91	25/1	26-43	0.53	0.63	0.17	0.14	0.12	0.15	0.14	0.03	3.46	0.07	0.14	<0.02	0.16	0.12	0.03	0.07	0.24
Dab	44E7	05/11/91	24/1	28-32	3.59	1.34	0.34	0.52	0.61	0.99	0.91	0.18	12.23	0.42	0.30	0.48	0.85	1.13	0.23	0.34	1.70
Sole	44E7	05/11/91	22/1	28-32	1.65	0.73	0.37	0.50	0.37	0.41	0.41	0.08	7.18	0.13	0.14	0.24	0.79	0.46	0.09	<0.02	0.64
Herring	45E6	15/02/91	25/1	18-22	1.25	0.37	0.17	0.37	0.34	0.82	0.63	0.29	7.47	0.32	0.25	0.94	0.85	0.60	0.46	0.30	1.62
Shellfish																					
Plaice	44E7	05/11/91	21/1	28-36	0.48	0.44	0.41	0.54	0.47	0.59	0.53	0.14	7.80	0.24	0.08	0.48	0.26	0.51	0.13	0.14	0.96
Nephrops	44E7	05/06/92	25/1	4.0-5.5	0.62	0.12	0.02	0.04	0.09	0.21	0.15	0.07	1.76	0.04	0.09	0.05	0.63	0.14	<0.02	0.02	0.16
Scallops	46E7	05/06/92	22/1	10-12	0.68	0.21	0.04	0.02	0.02	0.03	<0.02	<0.02	0.86	0.02	0.14	0.02	0.12	0.04	<0.02	<0.02	0.04
Crab	44E7	05/06/92	23/1	14-20	0.34	0.19	0.03	0.06	0.22	0.38	0.30	0.06	3.11	0.23	0.09	0.29	0.37	0.33	0.03	0.06	0.47

Table VI
North Sea (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Cod	58°28N 00°18E	06/03/91	20/4	38-66	33.5	<2	<2	26.1	28.8	68.5	60.0	21.7	512.6	13.8	1.4	60.7	23.1	64.0	17.3	20.5	101.8
sd								(6.28)	(12)	(22)	(20)	(2.05)		(2.15)		(17.11)	(3.92)	(21)	(4.86)	(7.18)	
Cod	58°30N 00°17E	08/06/89	10/1	39-54	12.5	<4	<4	30.7	62.6	101.0	87.4	25.5	767.8	<4	<4	56.3	7.1	67.9	23.8	22.6	127.6
Cod	58°39N 00°32E	08/06/89	8/1	26-69	19.2	<4	14.6	38.6	<4	126.2	103.6	31.9	787.3	<4	<4	61.3	19.4	104.0	24.5	<4	128.5
Cod	58°14N 00°32E	12/06/89	8/1	34-61	16.4	<4	<4	23.2	37.4	83.2	66.5	23.3	583.9	<4	<4	43.7	12.9	66.8	15.4	9.2	97.5
Cod	58°44N 01°04E	10/06/89	6/1	n/a	18.6	<4	<4	31.8	38.4	99.5	76.5	28.8	687.7	<4	<4	83.0	<4	113.0	30.8	28.9	183.0
Cod	58°15N 00°30E	11/09/90	16/1	28-53	49.3	<4	26.6	54.1	36.2	184.9	135.4	37.6	1194.4	21.8	10.6	125.6	57.8	175.9	89.1	29.1	328.2
Whiting	58°28N 00°18E	06/03/91	20/4	28-37	51.3	<2	<2	24.8	18.6	48.9	45.1	20.1	393.8	11.6	2.1	58.3	24.9	68.8	20.0	66.4	135.2
sd									(7)	(20)	(16)			(1.06)	(0.14)	(16.72)	(5.10)	(32)	(5.42)	(55)	
Whiting	58°30N 00°17E	08/06/89	10/1	26-32	27.7	6.2	13.4	46.8	62.5	142.8	120.3	37.5	1073.6	14.4	<4	63.5	<4	185.4	26.9	<4	243.9
Whiting	58°39N 00°32E	08/06/89	10/1	26-29	30.3	<4	<4	23.0	28.7	58.8	47.6	17.4	439.0	<4	<4	76.9	26.2	83.1	28.7	38.1	180.9
Whiting	58°14N 00°32E	12/06/89	10/1	25-38	29.0	<4	17.1	41.0	42.4	120.8	46.4	29.3	742.4	10.6	<4	88.4	16.9	145.1	31.0	45.0	254.1
Whiting	58°44N 01°04E	10/06/89	10/1	n/a	35.3	13.8	26.2	102.1	112.4	250.8	199.3	67.5	1930.3	35.4	12.1	130.3	9.1	283.5	50.5	3.8	377.9
Whiting	56°30N 00°30E	12/09/90	20/1	24-30	55.7	<4	<4	29.0	27.6	64.1	58.0	13.6	480.7	23.2	9.5	61.1	38.8	90.3	16.5	16.5	130.4
Whiting	56°30N 01°30E	12/09/90	20/1	25-29	54.5	<4	<4	26.8	29.7	63.3	57.4	15.8	482.2	21.8	4.4	27.9	23.8	91.7	13.5	13.5	123.1
Haddock	58°28N 00°18E	06/03/91	20/4	27-39	41.9	<2	<2	33.1	20.3	53.2	45.7	21.9	380.8	10.0	1.5	20.4	19.1	40.8	10.3	14.9	51.1
sd									(13)	(25)	(23)	(9.64)		(2.59)		(4.54)	(7.03)	(24)	(5)	(7.40)	
Haddock	58°30N 00°17E	08/06/89	10/1	27-36	20.1	<4	<4	12.1	45.2	118.6	88.4	35.7	749.9	8.5	6.6	18.2	14.1	41.1	15.1	<4	56.2
Haddock	58°39N 00°32E	08/06/89	10/1	29-41	21.0	<4	<4	<4	46.1	109.4	81.1	31.1	669.0	11.0	6.1	21.3	<4	36.9	7.5	9.7	54.1
Haddock	58°14N 00°32E	12/06/89	10/1	24-40	29.7	<4	<4	13.6	27.3	66.5	42.8	20.0	425.6	<4	<4	53.8	3.9	41.9	17.6	26.3	98.1
Haddock	58°44N 01°04E	10/06/89	10/1	n/a	30.3	<4	<4	16.8	44.1	149.9	103.1	46.2	901.8	11.7	5.1	26.0	11.9	78.0	10.9	<4	103.6
Witch	58°28N 00°18E	06/03/91	16/4	27-37	20.5	<2	7.9	34.7	36.1	42.2	50.3	13.2	441.3	2.2	1.9	2.6	5.0	15.6	<2	<2	15.6
sd								(15)	(16)	(16)	(17)	(5)		(0.45)	(0.46)	(0.90)	(1.05)	(5)			
Witch	58°28N 00°18E	01/06/89	9/1	27-36	15.8	9.5	<2	14.1	20.3	26.4	23.7	7.3	253.5	2.4	<2	<2	<2	15.22	<2	<2	15.2
Dab	56°30N 00°30E	12/09/90	20/1	25-33	22.0	5.1	10.4	26.1	27.0	58.0	48.0	12.4	467.6	13.6	6.1	62.8	17.4	83.5	11.7	10.0	111.8
Dab	56°30N 01°30E	12/09/90	20/1	18-27	17.0	<4	<4	8.2	12.0	36.6	26.5	7.8	227.7	4.4	<4	7.7	6.3	43.6	3.2	2.1	48.9
Fish Muscle																					
Cod	58°28N 00°18E	06/03/91	25/5	38-66	1.05	0.18	0.10	0.12	0.12	0.27	0.25	0.08	2.80	0.10	0.12	0.18	0.17	0.36	0.07	0.07	0.55
sd						(0.07)	(0.03)	(0.05)	(0.05)	(0.08)	(0.08)	(0.02)		(0.03)	(0.07)	(0.05)	(0.02)	(0.08)	(0.05)	(0.03)	
Cod	58°28N 00°18E	01/06/89	10/1	29-53	0.37	<0.04	<0.04	0.91	1.34	2.09	1.57	0.55	16.15	0.14	0.13	0 26	0.25	1.23	0.13	<0.04	1.36
Cod	58°30N 00°17E	08/06/89	10/1	39-61	0.38	0.05	0.07	0.33	0.50	0.77	0.73	0.19	6.60	0.09	0.01	0.22	0.10	0.53	0.07	0.16	0.76
Cod	58°39N 00°32E	08/06/89	8/1	26-64	0.41	0.07	<0.04	0.26	0.41	0.78	0.70	0.21	6.08	0.11	0.02	0.23	0.14	0.59	0.06	0.16	0.81
Cod	58°14N 00°32E	12/06/89	8/1	34-61	0.22	<0.04	<0.04	0.21	0.33	0.79	0.65	0.21	5.48	0.10	0.01	0.20	0.12	0.62	0.05	0.11	0.78
Cod	58°15N 00°30E	11/09/90	15/1	28-55	0.61	<0.04	<0.04	<0.04	<0.04	0.13	0.11	<0.04	0.60	<0.04	0.02	0.05	0.07	0.13	0.04	0.04	0.21
Whiting	58°28N 00°18E	06/03/91	10/1	29-37	n/a	0.24	0.12	0.07	0.06	0.16	0.14	<0.04	1.98	0.10	0.07	0.12	0.18	0.34	0.04	0.06	0.45
Whiting	58°28N 00°18E	01/06/89	10/1	27-33	0.49	<0.04	<0.04	1.37	0.88	1.90	1.55	0.50	15.50	0.18	<0.02	2.67	0.58	2.32	0.85	1.68	5.33
Whiting	58°30N 00°17E	08/06/89	10/1	25-32	0.98	<0.02	<0.02	<0.02	0.05	0.13	0.11	<0.02	0.73	<0.02	0.02	0.08	0.04	0.17	0.02	0.07	0.27
Whiting	58°39N 00°32E	08/06/89	10/1	26-29	0.55	<0.02	<0.02	<0.02	<0.02	0.11	<0.02	<0.02	0.28	<0.02	0.03	0.19	0.17	0.14	0.08	0.04	0.26
Whiting	58°14N 00°32E	12/06/89	10/1	24-38	0.51	<0.02	<0.02	0.20	0.22	0.61	0.47	0.18	4.20	0.14	<0.02	0.23	0.07	0.50	0.07	0.23	0.84
Whiting	58°15N 00°30E	11/09/90	19/1	27-41	0.56	<0.02	<0.02	<0.02	0.06	0.15	0.13	<0.02	0.85	0.06	0.02	0.04	0.06	0.16	0.02	0.02	0.20
Haddock	58°28N 00°18E	06/03/91	10/1	30-39	n/a	0.12	0.07	<0.02	<0.02	0.08	0.06	<0.02	0.83	0.05	0.09	0.07	0.20	0.13	0.03	0.03	0.21
Haddock	58°28N 00°18E	01/06/89	10/1	29-35	0.63	<0.02	<0.02	<0.02	0.44	1.08	0.72	0.33	6.43	<0.02	0.64	14.38	1.60	0.36	2.37	3.79	6.52
Haddock	58°30N 00°17E	08/06/89	10/1	27-36	0.42	<0.02	<0.02	<0.02	0.08	0.24	0.18	0.08	1.45	0.04	0.02	0.04	0.05	0.09	<0.02	0.03	0.12
Haddock	58°39N 00°32E	08/06/89	10/1	28-41	0.42	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.04	0.07	<0.02	0.02	0.04	0.06
Haddock	58°14N 00°32E	12/06/89	10/1	24-40	0.20	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	0.04	0.06	<0.02	0.02	<0.02	0.02
Witch	58°28N 00°18E	06/03/91	16/4	27-37	n/a	0.30	0.16	0.23	0.21	0.25	0.32	0.08	3.13	0.04	0.04	0.04	0.04	0.43	0.02	0.01	0.45
sd						(0.03)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.04)		(0.01)	(0.03)	(0.01)	(0.02)	(0.06)	(0.01)		
Witch	58°28N 00°18E	01/06/89	9/1	27-36	1.86	<0.08	<0.08	<0.08	<0.08	<0.08	0.34	<0.08	0.85	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	<0.08	
Herring	45F0	01/01/91	25/5	23-28	4.20	1.80	<1	3.50	2.30	6.70	6.60	1.70	56.50	2.30	0.43	2.79	2.30	10.20	1.70	1.30	13.20
sd								(1.24)	(0.77)	(2.26)	(2.27)	(0.62)		(0.89)	(0.30)	(1.25)	(1.09)	(3.59)	(0.67)	(0.54)	
Herring	43F1	31/01/91	25/1	22-29	2.00	0.64	0.39	0.74	0.62	1.39	1.19	0.35	13.31	0.42	0.51	1.97	2.23	0.87	0.94	0.65	2.72
Herring	41F2	31/01/91	25/1	22-27	2.60	0.40	0.35	0.52	0.45	0.99	0.87	0.20	9.45	0.29	0.10	0.39	0.62	0.51	0.21	0.16	0.97

Table VI (continued)
North Sea (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Shellfish																					
Nephrops	58°07N 00°04E	07/01/89	9/1	22-25	0.08	<1	<1	<1	<1	<1	<1	<1	<1	<1	1.25	1.64	<0.5	<1	<0.5	<0.5	<0.5
Nephrops	58°28N 00°18E	01/06/89	10/1	5-6.5	0.44	<0.04	<0.04	<0.04	0.31	0.16	0.44	0.08	2.48	<0.04	<0.04	<0.04	<0.04	0.33	<0.04	<0.04	0.33
Nephrops	58°28N 00°18E	01/06/89	10/1	n/a	0.49	<0.04	<0.04	<0.04	0.27	0.28	0.22	<0.04	1.93	<0.04	<0.04	<0.04	<0.04	0.13	<0.04	<0.04	0.13
Nephrops	58°28N 00°18E	06/03/91	50/2	n/a	n/a	0.27	0.12	0.11	1.02	0.81	0.99	0.20	8.80	0.04	0.04	0.07	<0.02	0.46	<0.02	<0.02	0.48
Pandalus	58°28N 00°18E	06/03/91	50/2	n/a	n/a	0.36	0.15	0.16	0.24	0.47	0.32	0.13	4.58	0.13	<0.02	0.23	<0.02	0.49	<0.02	<0.02	0.49
Pandalus	58°28N 00°18E	01/06/89	60/1	n/a	0.74	<0.04	<0.04	0.36	0.33	0.35	0.42	<0.04	3.78	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04

Table VII
Orkney and Shetland (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Muscle																					
Haddock	48E9	15/02/92	26/1	26-32	0.56	0.36	0.09	0.07	0.06	0.10	0.08	0.02	1.95	0.07	0.08	0.11	0.09	0.09	<0.02	<0.02	0.10
Plaice	48E8	15/02/92	25/1	22-36	0.52	0.19	0.08	0.07	0.07	0.11	0.11	0.03	1.65	0.04	0.06	0.12	0.08	0.13	0.02	<0.02	0.16
Herring	50E9	31/01/91	25/1	27-30	1.20	0.31	0.23	0.56	0.49	1.27	0.83	0.32	10.03	<0.1	0.53	2.38	1.26	1.58	0.76	0.36	2.97
Herring	51E8	31/01/91	25/1	26-36	1.10	0.27	0.21	0.39	0.34	0.82	0.61	0.20	7.08	0.24	0.26	1.26	0.72	1.03	0.58	0.35	2.29
Herring	47E7	31/01/91	25/1	24-29	2.50	0.43	0.14	0.25	0.21	0.43	0.35	0.12	4.82	0.29	0.26	0.91	0.75	0.32	0.28	0.22	1.05
Shellfish																					
Scallops	47E7	22/06/92	25/1	10-12	0.55	0.13	<0.01	<0.01	<0.01	0.03	0.02	<0.01	0.50	0.02	0.11	<0.01	0.10	0.04	0.01	<0.01	0.06
Crab	47E7	22/06/92	22/1	16-18	0.29	0.17	0.03	0.03	0.04	0.09	0.07	0.01	1.12	0.09	0.11	0.17	0.25	0.10	0.02	<0.01	0.12

Table VIII
Minches (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Cod	58°33N 06°09W	17/11/91	11/1	39-58	63.5	3.4	3.9	6.5	7.5	22.9	15.1	5.7	162.2	8.4	5.1	25.2	21.3	25.0	9.5	5.4	47.2
Whiting	58°33N 06°09W	17/11/91	21/1	24-34	55.1	2.8	3.0	5.8	5.7	16.5	11.9	3.9	123.9	6.8	3.4	12.3	15.4	20.0	8.4	4.1	35.0
Dab	58°33N 06°09W	17/11/91	22/1	23-37	39.8	7.9	2.7	5.1	5.7	15.0	10.7	5.2	130.4	4.6	<1	7.8	7.9	15.3	2.0	2.5	19.7
Sole	58°33N 06°09W	17/11/91	19/1	19-30	12.8	2.9	1.7	1.8	1.7	3.5	2.6	0.9	37.6	2.9	<1	10.0	14.5	5.3	1.0	1.4	10.5
Plaice	58°33N 06°09W	17/11/91	25/1	27-34	21.7	4.6	2.5	3.2	2.6	4.1	3.2	1.0	52.9	3.5	<1	3.3	6.2	4.2	1.4	1.4	7.0
Fish Muscle																					
Cod	58°33N 06°09W	17/11/91	11/1	39-58	0.59	0.35	0.11	0.11	0.10	0.12	<0.02	0.03	2.04	0.08	0.12	0.12	0.15	0.11	0.04	0.02	0.22
Whiting	58°33N 06°09W	17/11/91	21/1	23-34	0.60	0.38	0.14	0.13	0.10	0.13	0.11	0.03	2.55	0.08	0.17	0.02	0.15	0.14	0.05	0.03	0.24
Haddock	58°33N 06°09W	17/11/91	26/1	21-40	0.55	0.38	0.37	0.49	0.31	0.28	0.27	0.04	5.35	0.15	0.08	0.18	0.14	0.10	0.04	0.03	0.26
Dab	58°33N 06°09W	17/11/91	22/1	23-37	0.84	0.37	0.18	0.24	0.20	0.33	0.26	0.08	4.15	0.11	0.05	0.24	0.18	0.33	0.07	0.07	0.53
Sole	58°33N 06°09W	17/11/91	19/1	19-30	0.69	0.39	0.09	0.10	0.09	0.20	0.15	0.04	2.65	0.22	0.06	0.55	0.80	0.30	0.09	0.10	0.54
Plaice	58°33N 06°09W	17/11/91	25/1	27-34	0.66	0.29	0.12	0.16	0.11	0.12	0.10	0.02	2.30	0.07	0.04	0.08	0.13	0.14	0.03	0.03	0.23
Megrim	58°33N 06°09W	17/11/91	9/1	31-45	1.06	0.42	0.09	0.10	0.08	0.12	0.10	0.03	2.35	0.08	0.14	0.07	0.20	0.12	0.05	<0.02	0.19
Herring	46E3	01/09/92	26/1	24-29	2.74	0.13	0.23	0.67	0.59	1.51	1.21	0.38	11.77	0.26	0.23	1.21	0.56	2.62	0.61	0.12	3.35
Shellfish																					
Scallops	44E3	18/06/92	24/1	10-12	0.50	0.14	0.03	0.02	0.02	0.04	0.02	<0.01	0.67	0.02	0.13	0.04	0.14	0.04	0.01	<0.01	0.06
Nephrops	44E3	30/09/92	25/1	3.5-5.5	0.57	0.11	0.03	0.02	0.09	0.13	0.11	0.03	1.33	0.04	0.09	0.06	0.54	0.07	<0.01	<0.01	0.07
Nephrops	57°49N 06°00W	09/01/89	10/1	38-44	0.08	<1	<1	<1	<1	<1	<1	<1	<1	<1	<0.5	5.74	0.47	<0.5	0.67	<0.5	0.67

Table IX
Eastern Atlantic (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Haddock	44E1	01/09/92	25/1	28-36	67.7	4.7	<1	11.0	9.7	21.8	17.0	5.3	173.8	20.9	10.6	39.5	16.9	47.2	7.9	1.1	56.2
Haddock	56°29N 07°31W	20/11/91	12/1	27-38	53.0	2.6	<1	2.1	3.6	11.9	8.0	3.9	80.3	3.8	3.3	6.0	16.2	9.6	2.6	<0.5	12.2
Whiting	56°29N 07°31W	20/11/91	26/1	27-38	54.6	12.4	3.4	6.3	8.0	21.0	14.9	6.5	181.2	6.7	2.3	15.7	9.9	22.4	7.6	5.4	37.7
Plaice	56°29N 07°31W	20/11/91	4/1	30-40	16.0	2.9	<1	<1	<1	<1	<1	<1	7.3	<1	1.0	1.8	2.6	0.5	0.7	<0.5	2.0
Fish Muscle																					
Haddock	44E1	01/09/92	25/1	28-35	0.56	0.06	<0.01	0.02	0.02	0.04	<0.01	0.01	0.37	0.11	0.03	0.02	0.05	0.08	<0.01	<0.01	0.08
Haddock	56°29N 07°31W	20/11/91	12/1	27-38	0.40	0.33	0.10	0.13	0.09	0.08	0.08	0.02	2.08	0.09	0.03	0.09	0.10	0.05	<0.01	<0.01	0.05
Whiting	56°29N 07°31W	20/11/91	26/1	27-38	0.59	0.60	0.33	0.38	0.26	0.26	0.22	0.06	5.28	0.08	0.16	0.03	0.13	0.14	0.04	0.04	0.29
Plaice	56°29N 07°31W	20/11/91	4/1	30-40	0.56	0.65	0.15	0.18	0.19	0.29	0.23	0.06	4.38	0.08	<0.04	0.11	0.14	0.28	0.06	0.04	0.42
Megrim	56°29N 07°31W	20/11/91	9/1	26-38	0.70	0.34	0.09	0.07	0.07	0.10	0.07	0.02	1.90	0.09	0.07	0.08	0.14	0.10	0.05	0.04	0.21
Mackerel	56°29N 07°31W	20/11/91	25/5	25-33	6.40	1.40	0.54	1.47	1.38	3.13	2.35	1.12	28.48	0.53	0.51	3.08	1.62	1.81	1.25	1.46	6.11
Mackerel	41E2	01/09/92	25/1	26-32	9.65	0.35	<0.1	0.31	0.33	1.00	1.05	0.23	8.19	0.40	0.67	0.91	1.33	0.73	<0.04	<0.04	0.73
Mackerel	44E0	30/11/90	10/1	24-34	13.06	3.22	0.64	1.23	1.11	2.52	1.83	0.53	27.70	1.37	0.99	3.91	3.43	1.78	1.41	1.39	6.05
Mackerel	37D9	03/12/90	10/1	26-32	11.40	3.46	0.74	1.94	1.69	4.39	3.27	1.28	41.93	1.28	0.85	3.03	3.25	2.02	1.39	1.53	5.43
Herring	41E2	01/09/92	25/1	24-29	0.78	0.10	0.12	0.29	0.25	0.67	0.58	0.18	5.46	0.21	0.24	0.68	0.39	0.93	0.25	<0.04	1.23
Herring	44E0	30/11/90	10/1	22-39	3.58	1.55	0.63	1.36	1.34	2.56	2.16	0.70	25.75	0.93	0.44	2.84	1.57	4.07	1.30	0.76	8.44
Herring	41E2	01/12/90	10/1	25-28	4.76	1.10	0.46	0.81	0.70	1.35	1.01	0.31	14.35	0.88	0.50	1.99	1.79	1.41	1.05	0.55	3.30
Herring	37D9	03/12/90	10/1	27-30	4.55	1.08	0.50	<0.1	1.02	1.95	1.54	0.54	16.56	0.76	0.57	2.43	1.71	1.80	1.31	0.69	4.31
Herring	33D8	04/12/90	10/1	24-29	1.93	1.00	0.42	1.03	1.02	2.78	2.31	1.00	23.89	0.32	0.22	1.15	0.61		0.64	0.20	1.03

Table X
Firth of Clyde (µg/kg wet weight)

	Location	Sampling date	No. of fish/ pools	Length (cm)	% Lipid	CB28	CB52	CB101	CB118	CB153	CB138	CB180	Arochlor 1254 EQ	HCB	G-HCH	Total Chlordanes	Dieldrin	4,4´-DDE	4,4´-DDD	4,4´-DDT	SUM DDTs
Fish Liver																					
Cod	55°41N 05°00W	18/05/90	20/4	26-35	29.40	43.30	66.90	190.15	254.30	633.40	466.40	426.70	5,202.93	<1	<1	51.10	99.18	266.70	176.60	16.60	499.10
sd						(17.72)	(24.08)	(13.83)	(49.64)	(141.13)	(159.72)	(182.18)				(6.00)	(35.73)	(28.52)	(60.58)	(6.77)	
Cod	55°41N 05°08W	22/11/91	6/1	29-43	47.00	11.48	29.52	54.79	99.74	282.21	194.94	135.92	2,021.50	4.93	8.31	29.61	67.75	nq	100.18	35.15	135.33
Cod	55°31N 04°53W	20/05/90	8/1	22-30	23.20	5.18	17.47	70.72	133.62	434.80	295.40	207.32	2,911.28	4.09	1.74	31.00	37.85	196.76	70.39	8.08	291.06
Cod	55°25N 05°20W	11/06/88	7/1	27-38	35.75	9.53	26.97	115.07	159.90	377.30	295.45	224.70	3,022.43	9.74	17.58	79.93	131.90	nq	156.80	89.50	246.30
Cod	55°06N 05°30W	20/05/90	10/1	48-53	47.20	3.60	6.02	17.22	25.38	75.92	53.84	24.23	515.51	6.94	4.48	23.89	30.72	46.41	26.72	6.31	83.29
Whiting	55°41N 05°00W	22/11/91	25/1	25-29	59.50	8.55	21.54	45.58	48.07	139.77	96.21	55.08	1,037.00	7.40	11.88	31.09	66.20	93.18	97.95	28.36	246.31
Whiting	55°37N 04°43W	22/05/90	5/1	24-26	52.60	10.79	35.13	113.89	115.10	355.32	267.41	142.69	2,600.82	9.96	3.66	32.10	55.54	230.66	139.04	33.97	421.87
Whiting	55°36N 04°48W	19/05/90	5/1	23-26	37.40	6.92	19.74	59.30	84.39	271.48	195.94	119.27	1,892.63	5.75	4.07	58.33	51.40	232.50	190.69	43.06	495.31
Whiting	55°06N 05°30W	20/05/90	10/1	26-35	36.20	5.50	9.79	20.36	38.57	103.06	93.97	46.64	794.71	5.72	4.25	41.91	48.85	94.35	112.50	27.52	249.50
Haddock	55°41N 05°00W	18/05/90	10/1	24-28	42.80	11.03	20.66	42.92	59.35	164.64	118.86	80.21	1,244.17	4.56	3.88	19.12	52.55	64.09	97.26	14.62	192.74
Haddock	55°06N 05°30W	20/05/90	10/1	23-28	32.80	6.13	9.12	29.19	50.92	146.87	107.76	49.49	998.70	5.23	2.27	15.64	25.57	98.66	69.18	24.86	195.56
Hake	55°41N 05°00W	18/05/90	10/1	32-42	53.30	5.36	17.50	43.02	43.67	123.68	93.95	53.76	952.35	6.19	<0.05	13.03	35.77	90.27	60.35	16.76	180.66
Hake	55°41N 05°00W	22/11/91	25/1	28-37	54.80	9.86	30.56	67.59	58.83	172.23	124.29	67.89	1,328.15	8.63	9.18	35.46	71.58	113.37	148.78	35.02	338.72
Hake	55°37N 04°53W	22/05/90	5/1	29-42	50.00	8.38	33.95	96.30	89.82	253.09	198.15	113.61	1,983.20	6.90	5.02	56.59	100.28	148.99	213.84	36.14	445.47
Hake	55°36N 04°48W	19/05/90	6/1	35-39	67.60	9.90	29.97	69.69	64.50	169.70	139.37	71.60	1,386.80	11.82	<0.05	19.94	67.72	128.70	110.42	33.31	294.37
Hake	55°31N 04°53W	19/05/90	6/1	36-52	57.60	6.44	22.99	58.67	62.17	181.11	132.46	76.67	1,351.29	10.28	<0.05	36.75	12.89	136.50	111.68	13.85	292.39
Hake	55°24N 05°17W	20/05/90	10/1	33-55	54.40	6.69	22.02	58.76	63.98	171.10	137.58	72.63	1,331.87	9.70	<0.05	21.77	10.76	134.57	156.45	13.17	328.77
Saithe	55°41N 04°59W	18/05/90	10/1	31-35	24.30	19.23	46.30	127.16	106.04	341.37	290.02	120.04	2,625.40	7.93	3.72	88.90	81.59	258.82	296.99	10.87	597.64
Saithe	55°39N 05°02W	11/06/88	10/1	28-30	44.63	183.90	230.70	371.70	272.90	502.80	362.30	263.60	5,469.75	63.20	12.70	116.38	465.00	nq	415.90	116.50	568.50
Saithe	55°33N 04°55W	21/05/90	10/1	31-37	45.20	22.46	50.67	113.98	95.19	269.74	222.20	98.82	2,182.65	13.48	5.11	100.00	104.44	252.33	258.26	40.97	592.93
Plaice	55°41N 05°08W	10/11/91	25/1	n/a	13.30	15.13	12.33	18.95	19.66	62.21	40.91	32.71	436.30	1.72	5.84	8.54	24.93	19.01	31.35	5.26	63.61
Plaice	55°39N 05°02W	11/06/88	9/1	21-28	23.80	27.45	25.53	50.04	56.73	134.16	88.40	86.60	1,172.38	10.74	nq	nq	nq	nq	nq	nq	nq
Plaice	55°41N 05°01W	20/05/90	18/1	n/a	22.20	11.66	14.84	23.02	23.94	72.15	46.08	38.14	574.54	3.61	2.04	6.65	27.26	32.22	25.76	<0.5	64.77
Plaice	55°37N 04°53W	20/05/90	25/1	n/a	15.94	3.12	3.09	7.71	9.79	38.47	26.91	18.06	267.86	1.86	1.65	1.42	10.91	27.24	17.62	<0.2	48.65
Plaice	55°36N 04°48W	20/05/90	25/1	n/a	11.01	2.47	2.47	4.53	7.51	24.58	16.33	9.77	169.17	1.41	0.90	0.94	7.23	22.84	9.90	<0.2	34.84
Plaice	55°25N 05°10W	20/05/90	25/1	n/a	30.00	22.96	34.65	39.74	32.28	86.91	55.16	42.56	785.64	7.45	3.55	11.56	40.66	47.69	33.76	<0.2	88.65
Plaice	55°25N 05°10W	11/06/88	10/1	23-32	9.20	1.94	2.61	3.43	4.41	18.77	13.40	8.43	132.43	0.44	nq	nq	nq	nq	nq	nq	nq
Plaice	55°06N 05°30W	20/05/90	4/1	n/a	12.33	2.87	1.30	2.22	2.98	7.06	5.76	2.60	61.95	1.62	1.46	0.91	3.45	7.91	3.68	<0.5	12.52
Fish Muscle																					
Cod	55°41N 05°08W	22/11/91	6/1	29-43	0.55	0.29	0.16	0.21	0.32	0.80	0.58	0.41	6.93	0.03	0.09	0.05	0.30	0.48	0.23	0.04	0.785
Cod	55°25N 05°20W	11/06/88	7/1	27-38	0.55	0.40	<0.4	0.64	0.99	4.71	2.32	2.05	27.78	<0.4	1.14	1.51	0.89	<0.4	1.05	<0.4	1.05
Whiting	55°41N 05°08W	22/11/91	25/1	25-29	0.63	0.64	0.20	0.21	0.19	0.40	0.29	0.18	5.28	0.06	0.18	0.13	0.39	0.27	0.23	0.07	0.67
Hake	55°41N 05°08W	22/11/91	25/1	28-37	1.86	0.68	0.68	1.32	1.19	2.85	2.26	1.12	25.25	0.16	0.25	0.78	1.76	2.21	2.83	0.34	6.29
Saithe	55°39N 05°02W	11/06/88	10/1	28-30	0.83	1.66	2.06	3.18	1.51	4.98	1.93	1.51	42.08	<0.4	0.70	2.78	4.21	<0.4	2.45	0.97	3.42
Plaice	55°39N 05°02W	11/06/88	9/1	21-28	0.53	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	0.47	4.97	0.45	<0.4	<0.4	<0.4	<0.4
Plaice	55°41N 05°08W	22/11/91	27/1	19-28	0.61	0.71	0.29	0.34	0.35	0.78	0.56	0.39	8.55	0.08	0.17	0.16	0.61	0.62	0.48	0.21	1.46
Plaice	55°25N 05°20W	11/06/88	10/1	23-32	0.70	0.17	<0.4	<0.4	<0.4	1.85	<0.4	<0.4	5.05	<0.4	0.90	7.57	1.57	<0.4	0.88	<0.4	0.88
Herring	55°41N 05°08W	22/11/91	25/1	26-32	5.03	1.83	2.46	4.46	3.82	8.23	6.40	2.99	75.48	0.76	0.77	2.95	4.50	10.82	6.39	1.35	20.34
Herring	55°25N 05°20W	11/06/88	10/1	25-33	7.25	1.57	4.42	12.49	10.23	22.14	18.20	8.70	189.45	0.42	6.08	12.14	12.85	nq	19.72	6.97	26.69
Herring	55°45N 05°25W	17/07/91	25/5	27-31	8.50	2.94	3.93	6.82	5.71	13.55	10.38	5.02	120.88	<0.4	2.42	3.23	11.51	15.25	16.83	3.30	35.38
sd								(2.43)	(2.07)	(4.80)	(3.48)	(1.42)			(0.65)		(2.50)	(52.88)	(3.33)	(0.84)	
Shellfish																					
Nephrops	39E4	29/06/92	25/1	3.6-4.2	0.5	0.15	0.04	0.08	0.44	1.08	0.73	0.37	7.24	0.05	0.13	0.10	1.97	0.69	<0.01	0.02	0.73
Nephrops	55°42N 05°01W	11/01/89	11/1	28-40	0.10	0.98	<0.5	0.53	0.15	3.12	0.97	1.31	17.65	<0.5	0.50	4.30	4.47	<0.5	4.65	<0.5	7.23

Table XI
Summary of contaminant levels in cod liver and muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	2,021–5,203	1,301	325	512–1194		162	
	7–28	**5.1**	**3.60**	**0.6–16**		**2**	
HCB	<1–9.7	39	8.6	<4–22		8.4	
	0.03	**0.2**	**0.06**	**<0.04–0.14**		**0.08**	
G-HCH	<1–17.6	<2	3.1	<4–11		5.1	
	0.09–1.14	**0.06**	**0.19**	**0.01–0.12**		**0.12**	
Dieldrin	38–132	25.9	27.7	<4–58		21.3	
	0.3–0.9	**0.2**	**0.12**	**0.07–0.25**		**0.15**	
4,4´-DDE	197–267	110	44.6	64–175		25	
	0.5	**0.3**	**0.2**	**0.13–1.23**		**0.04**	
4,4´-DDD	70–177	25.6	4.8	15–89		9.5	
	0.2–1.05	**0.09**	**0.04**	**0.04–0.13**		**0.04**	
4,4´-DDT	8–89	21.3	11.1	<4–29		5.4	
	0.04	**0.05**	**0.03**	**0.04–0.16**		**0.02**	
Chlordanes	31–80	57.2	32.5	44–126		25.2	
	0.05–1.5	**0.13**	**0.19**	**0.05–0.26**		**0.12**	

Muscle data

Table XII
Summary of contaminant levels in whiting liver and muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	1,893–2,601	226	445	439–1,930		124	181
	5.3	**7.5**	**3**	**0.3–15.5**		**2.6**	**5.3**
HCB	5.7–10	20	13.9	<4–35		6.8	6.7
	0.06	**0.3**	**0.06**	**<0.02–0.18**		**0.08**	**0.08**
G-HCH	3.7–12	3.7	3.2	<4–12.1		3.4	2.3
	0.18	**0.2**	**0.13**	**<0.02–0.07**		**0.08**	**0.16**
Dieldrin	49–66	22	13.3	9–39		15.4	9.9
	0.39	**0.2**	**0.14**	**0.04–0.58**		**0.15**	**0.13**
4,4´-DDE	93–233	29	45	83–283		20	22.4
	0.27	**0.3**	**0.18**	**0.14–2.3**		**0.15**	**0.14**
4,4´-DDD	98–190	21	5.7	13.5–50.5		8.4	7.6
	0.23	**0.1**	**0.05**	**0.02–0.85**		**0.05**	**0.04**
4,4´-DDT	28–43	9.1	10	<4–66		4.1	5.4
	0.07	**0.06**	**0.08**	**0.02–1.7**		**0.03**	**0.04**
Chlordanes	31–58	15.6	21.8	28–130		12.3	15.7
	0.13	**0.04**	**0.05**	**0.04–2.7**		**0.02**	**0.03**

Muscle data

Table XIII
Summary of contaminant levels in haddock liver and muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	1,244		225	381–902			80–174
			3.5	**<0.02–6.4**	**1.95**	**5.4**	**0.4–2.1**
HCB	4.6		6.9	<4–12			3.8–21
			0.07	**<0.02–0.05**	**0.07**	**0.15**	**0.09–0.11**
G-HCH	3.9		3.1	<4–6.6			3.3–10.6
			0.14	**0.02–0.64**	**0.08**	**0.08**	**0.03**
Dieldrin	52.6		17.6	<4–19			16
			0.16	**0.05–106**	**0.09**	**0.14**	**0.0–.0.1**
4,4´-DDE	64		20.8	37–78			10–47
			0.12	**<0.02–0.36**	**0.09**	**0.1**	**0.05–0.08**
4,4´-DDD	97		4.3	7.5–17.6			2.6–7.9
			0.03	**<0.02–2.4**	**<0.02**	**0.04**	**<0–01**
4,4´-DDT	14.6		6.5	<4–26			<0.5–1.1
			0.07	**<0.02–2.8**	**<0.02**	**0.03**	**<0.01**
Chlordanes	19.1		21.7	18–54			6–40
			<0.02	**0.04–14.4**	**0.11**	**0.18**	**0.02–0.09**

Muscle data

Table XIV
Summary of contaminant levels in plaice liver and muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	132–1,172		129		1.7	53	7.3
	<0.4–8.9		**7.8**			**2.3**	**4.4**
HCB	0.4–10.7		4.2		0.04	3.5	<1
	<0.4		**0.24**			**0.07**	**0.08**
G-HCH	0.9–5.8		<1		0.06	<1	1
	0.2–1		**0.08**			**0.04**	**<0.04**
Dieldrin	7–41		13.1		0.08	6.2	2.6
	0.5–1.6		**0.26**			**0.13**	**0.14**
4,4´-DDE	19–48		13.9		0.13	4.2	0.5
	<0.4–0.6		**0.5**			**0.14**	**0.28**
4,4´-DDD	10–34		2.3		0.02	1.4	0.7
	<0.4–0.9		**0.13**			**0.03**	**0.06**
4,4´-DDT	<0.2–5.3		3.2		<0.02	1.4	<0.5
	<0.4		**0.14**			**0.03**	**0.04**
Chlordanes	1–12		9.1		0.12	3.3	1.8
	0.2–7.8		**0.48**			**0.08**	**0.14**

Muscle data

Table XV
Summary of contaminant levels in dab liver and muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls		831	169	228–468		130	
			12.2			**4.2**	
HCB		17.6	5.8	4–14		4.6	
			0.4			**0.07**	
G-HCH		6	1.9	<–6		<1	
			0.3			**0.05**	
Dieldrin		211	15.5	6–17		7.9	
			0.9			**0.18**	
4,4´-DDE		159	15	44–84		15.3	
			1.1			**0.3**	
4,4´-DDD		33	2.9	3–12		2	
			0.2			**0.07**	
4,4´-DDT		48	5.6	2–10		2.5	
			0.3			**0.07**	
Chlordanes		98	15	6–63		7.8	
			0.5			**0.2**	

Muscle data

Table XVI
Summary of contaminant levels in herring muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	76–189	23.8	7.5	9–57	4.8–10	11.8	5–26
HCB	<0.4–0.8	1.7	0.3	0.3–2.3	<0.1–0.3	0.3	0.2–0.9
G-HCH	0.8–6.1	1.6	0.3	0.1–0.5	0.3–0.5	0.2	0.2–0.6
Dieldrin	4.5–12.8	2.9	0.9	0.6–2.3	0.7–1.3	0.6	0.4–1.8
4,4´-DDE	10.8–15.3	2.3	0.6	0.5–10.2	0.3–1.6	2.6	0.9–4.1
4,4´-DDD	6.4–19.7	<0.8	0.5	0.2–1.7	0.3–0.8	0.6	0.3–1.3
4,4´-DDT	1.4–7	<0.8	0.3	0.2–1.3	0.2–0.4	0.1	<0.04–0.7
Chlordanes	3–12.1	<0.8	0.9	0.4–2.8	0.9–204	1.2	0.7–2.8

Table XVII
Summary of contaminant levels in Nephrops muscle (μg/kg wet weight)

	Firth of Clyde	Firth of Forth	Moray Firth	North Sea	Shetland, Orkney	Minches, Butt of Lewis	Atlantic
Chlorobiphenyls	7–18		1.8	<1–9		<1–1.3	
HCB	0.05		0.04	0.04		0.04	
G-HCH	0.1–0.5		0.09	<0.04–1.3		0.09	
Dieldrin	2–4.5		0.6	<0.5		0.5–0.8	
4,4´-DDE	<0.5–0.7		0.14	0.1–0.5		0.07	
4,4´-DDD	<0.01–4.7		<0.02	0.02–<0.5		<0.01–2.4	
4,4´-DDT	0.02		0.02	<0.02–<0.5		<0.5	
Chlordanes	0.1–4.3		0.05	0.07–1.6		0.06–23	

Table XVIII
JMG guidelines for chlorobiphenyls in biota (mg/kg)

Level	Fish muscle	Cod liver	Flounder liver	Crustacean
Lower	<0.01	<2.0	<0.05	<0.01
Medium	0.01–0.05	2.0–5.0	0.50–1.0	0.01–0.05
Upper	>0.05	>5.0	>1.0	>0.05

Table XIX

Maximum concentrations of organochlorine contaminants in liver and muscle of Scottish fish compared with guidance values for the assessment of possible hazards to human health (JMG document 17/3/10-E, 1992)

	Fish liver (µg/kg wet wt)			UK guidelines	Strictest European guidelines	
	Maximum	Mean				
Chlorobiphenyls	5,203	3,290	cod Clyde	–	5,000	Norway/Sweden
Hexachlorobenzene	39	36	cod Forth	100 E	50	Norway
Lindane	18	8	cod Clyde	50 E 2,000 MRL	200	Norway
Dieldrin	465	217	saithe Clyde	200–300 E 200 MRL	–	
Chlordanes	130	72	whiting North Sea	–	–	
4,4´-DDE	283	135	whiting North Sea	500 E	–	
4,4´-DDD	416	323	saithe Clyde	500 E	–	
4,4´-DDT	117	56	saithe Clyde	500 E	–	
Total DDT	598	596	saithe Clyde	5,000 MRL	5,000	Denmark/Germany

	Fish muscle (µg/kg wet wt)			UK guidelines	Strictest European guidelines	
	Maximum	Mean				
Chlorobiphenyls	189		herring Clyde	–	1,000	Norway
Hexachlorobenzene	1		herring Clyde	–	50	Norway
Lindane	6		herring Clyde	–	100	Finland
Dieldrin	13		herring Clyde	–	–	
Chlordanes	12		herring Clyde	–	–	
4,4´-DDE	15		herring Clyde	–	–	
4,4´-DDD	20		herring Clyde	–	–	
4,4´-DDT	7		herring Clyde	–	–	
Total DDT	35		herring Clyde	–	500	Finland

E - expected value in fish liver

MRL - Maximum Residue Limit in meat fat (FAO/WHO, 1987)

Discussion

Spatial Distribution

Hydrophobic compounds such as chlorobiphenyls (CBs) and organochlorine pesticides preferentially accumulate in fatty tissue. Increased lipid levels in tissue lead to higher body burdens of organochlorine contaminants primarily through equilibrium partitioning from the aqueous phase and from dietary intake (Duinker and Boon, 1986; Duursma *et al.*, 1986). As the lipid content of, for example, fish liver can vary between individuals and populations depending on sex, reproductive state, amount of food intake, disease state etc, differing contaminant concentrations can result in fish in similar environments. This variability must be removed if the influence of geographical area on contaminant concentration in biota is to be examined. The approach generally taken is to express contaminant concentrations in terms of tissue lipid weight as opposed to total weight. The resultant data primarily reflects "exposure" of biota to contaminants. Thus, areas can be ranked in terms of ambient contaminant levels. In considering Scottish waters, this has been done with representative data for a demersal roundfish (cod or whiting), demersal flatfish (plaice and dab), a pelagic fish (herring), and shellfish (*Nephrops* and crab). The results are shown in Figures 2 to 7.

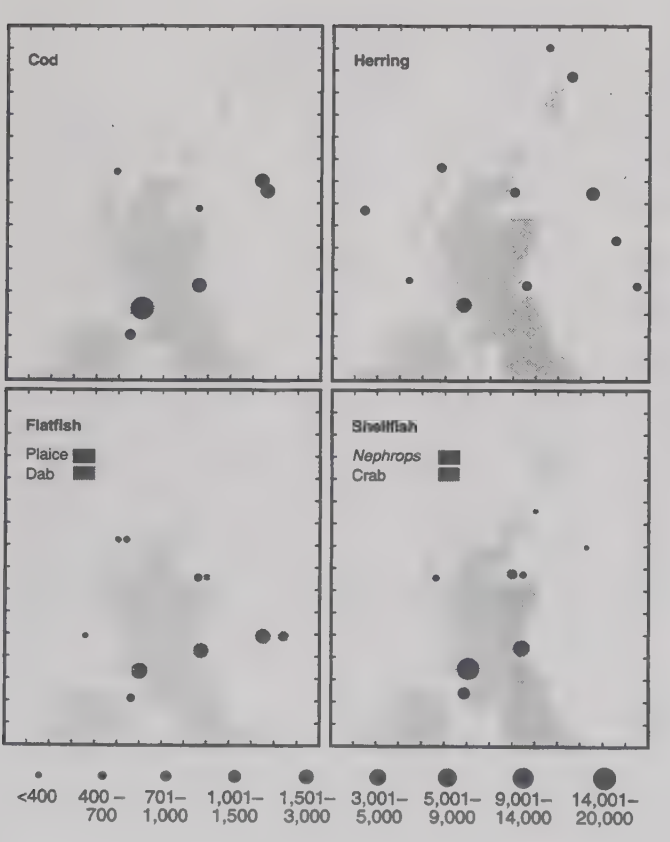

Figure 2.
Concentration of chlorobiphenyls in Scottish fish and shellfish as an Arochlor 1254 equivalent (μg/kg lipid).

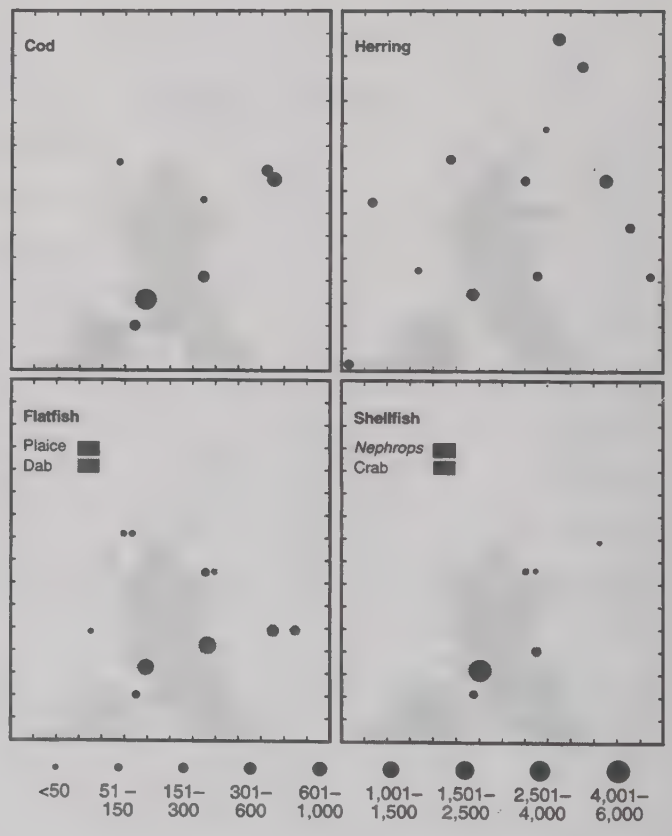

Figure 3.
Concentration of total DDT in Scottish fish and shellfish as a sum of 2,4´ and 4,4´-DDT,DDD and DDE (μg/kg lipid).

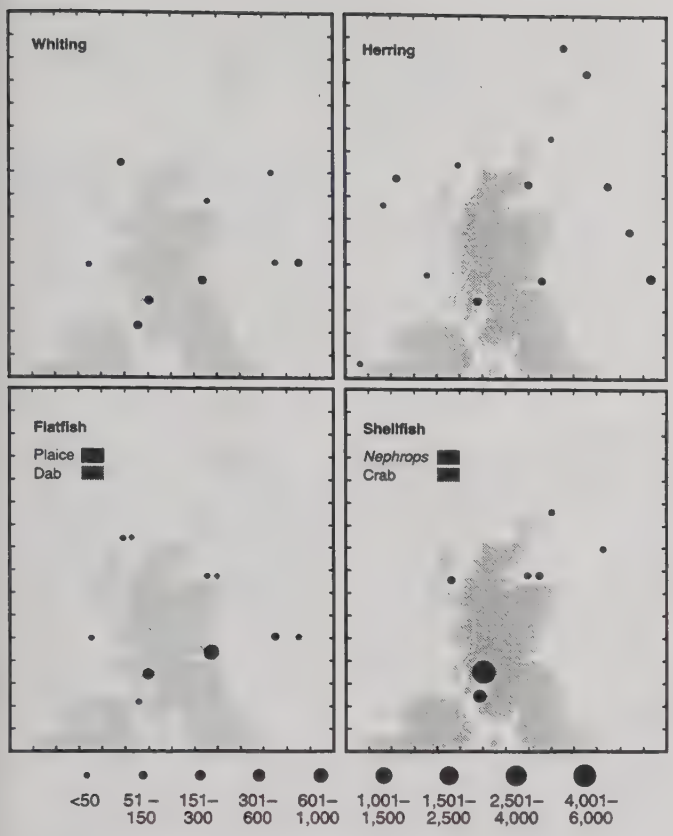

Figure 4.
Concentration of dieldrin in Scottish fish and shellfish (µg/kg lipid).

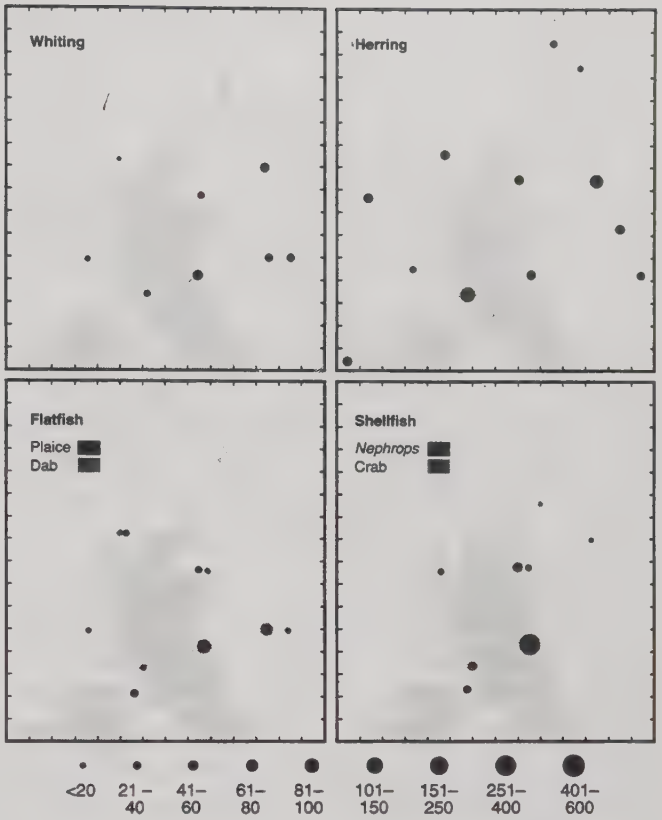

Figure 5.
Concentration of hexachlorobenzene in Scottish fish and shellfish (µg/kg lipid).

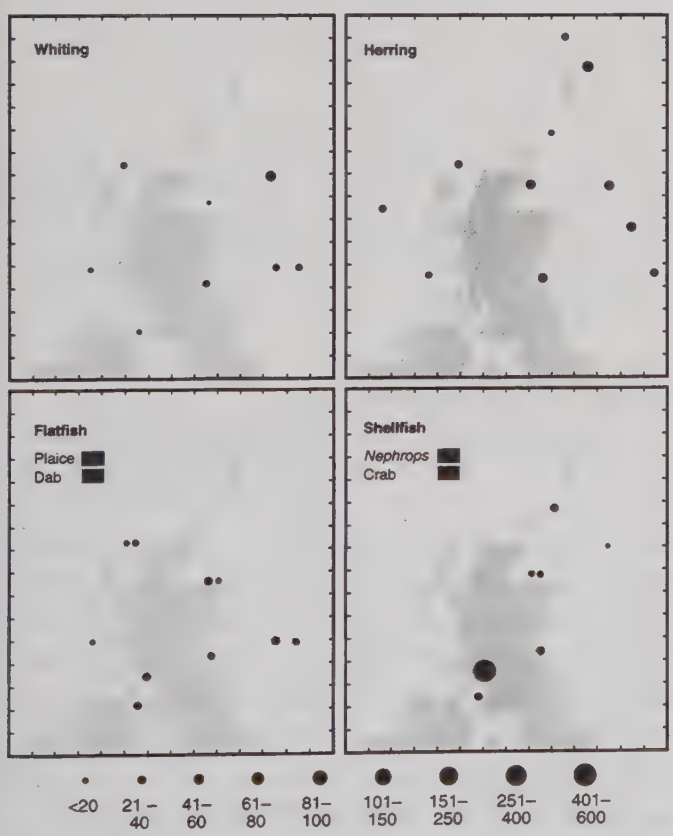

Figure 6.
Concentration of lindane (G-HCH) in Scottish fish and shellfish (µg/kg lipid).

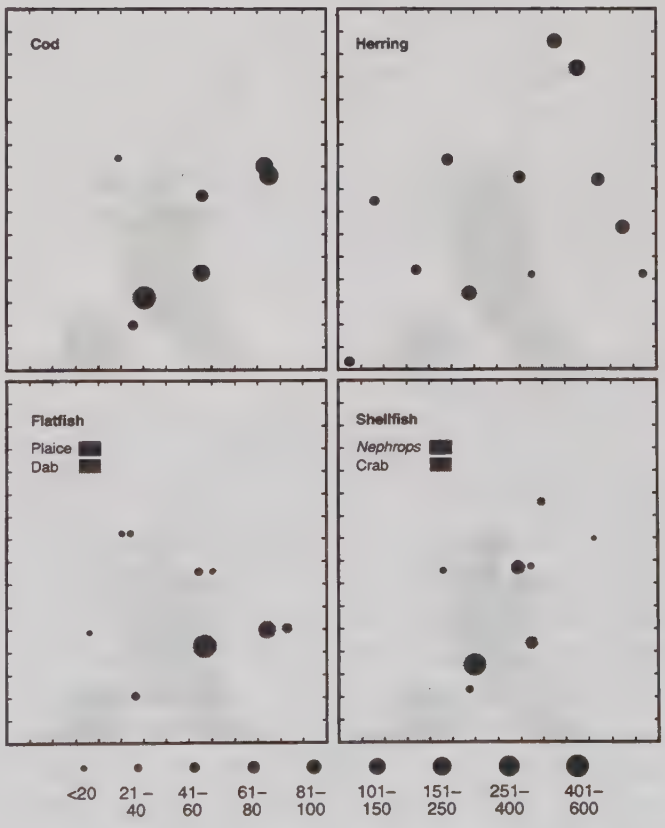

Figure 7.
Concentration of total chlordanes in Scottish fish and shellfish (µg/kg lipid).

Chlorobiphenyls

The distribution of CBs as an Arochlor 1254 equivalent was similar for all species. Highest concentrations were present in the Firth of Clyde, with 17,700 µg/kg lipid in cod liver and *Nephrops* muscle, followed by the Firth of Forth and the North Sea around the Piper Alpha site, these being some three to five times lower than in the Clyde. The data suggest decreasing CB concentrations from the Firth of Clyde into the North Channel in cod, plaice and *Nephrops*, east from the Firth of Forth into the North Sea in dab, and south-east from Piper Alpha in herring. Concentrations of CBs to the west and north of Scotland and in the Moray Firth were low, Atlantic values being less than 400µg/kg lipid for demersal fish and less than 800µg/kg lipid for pelagic fish.

The data reflect the known terrestrial inputs of CBs to Scottish waters. High sediment concentrations of CBs were present in some parts of the Clyde associated with the disposal of sewage sludge (Halcrow *et al.*, 1974; Kelly, unpublished observations). Industrial input and dumping of sewage sludge also occurs in the Forth. Release of CBs during the Piper Alpha incident may be responsible for the elevated levels observed in cod and herring at the site of the former platform. The concentration of CBs in herring muscle from this site is second only to that present in the northern Firth of Clyde (1,345 versus 1,456 µg/kg lipid).

DDT Compounds

In cod, herring and shellfish, the distribution of DDT compounds was similar to that of the CBs. Highest levels were present in the Firth of Clyde with 7,230 µg/kg lipid in *Nephrops* muscle and 1,698 µg/kg lipid in cod liver. Concentrations of less than 100 µg/kg lipid occurred to the north and west of the Scottish mainland with a minimum of 13 µg/kg lipid in plaice liver from west of Coll. Both cod and herring samples from the site of Piper Alpha contained higher levels of DDT compounds than those from neighbouring North Sea sites. Flatfish exhibited the highest concentrations of DDT compounds in the Firth of Forth with 2,007 µg/kg lipid in dab liver from the Isle of May taken in 1991. The variability of such measurements is illustrated by comparison of this sample with dab taken in 1992 further seaward at St Abb's Head where a lower DDT concentration of 515 µg/kg lipid, comparable with that found in Clyde plaice, was found. DDT concentrations declined eastward, as distance from the Forth increases, reaching 288 µg/kg some 400 km east.

Dieldrin

The distribution of dieldrin in flatfish was similar to that for DDT with a maximum of 1,025µg/kg lipid in Forth dab liver. A similar dieldrin concentration of 909 µg/kg lipid was present in a second sample taken the following year. This is considerably higher than the maximum concentration of 135 µg/kg found in whiting liver and herring muscle in the Firth of Clyde and suggests both a significant input of dieldrin to the Firth of Forth and a specific accumulative route in dab. Excluding these two areas, concentrations of dieldrin in fish were generally less than 100 µg/kg lipid. Shellfish contained higher concentrations than fish, with a maximum of 4,470 µg/kg in *Nephrops* muscle from the Firth of Clyde. A known input of dieldrin to the Clyde is derived from its use as a mothproofing agent by the carpet and textile industry prior to the 1970s. The greater concentrations of dieldrin present in shellfish relative to fish from the same areas may reflect differences in the ability of fish and crustaceans to eliminate dieldrin.

Chlordane Compounds

The concentration of chlordane compounds in demersal fish was highest in the Firths of Clyde and Forth and at the Piper Alpha site with a maximum of 475 µg/kg lipid in Forth dab liver. Demersal fish and crab from the Moray Firth contained chlordane concentrations which are two to four times higher than the lowest "Atlantic" values of 11 to 40 µg/kg lipid. The distribution in herring was considerably different, with the highest concentrations of 100 to 200 µg/kg lipid in fish from north of Shetland, and relatively low concentrations in fish from the Clyde and Forth. The relative uniformity of chlordane concentrations in herring sampled in

both nearshore and offshore waters suggests that the primary source of these compounds to the water column may be atmospheric input.

Hexachlorobenzene

With the exception of the Firth of Forth, the distribution of hexachlorobenzene (HCB) in fish is relatively uniform with concentrations generally less than 50 µg/kg lipid. Samples from the Firth of Forth had maximum HCB concentrations of 85 µg/kg lipid in dab liver, 52 µg/kg lipid in whiting liver and 554 µg/kg lipid in crab muscle. Dab samples demonstrated a concentration gradient eastwards declining to 26 µg/kg lipid, 400 km east of the Firth. A well established and declining input of HCB occurs from the chemical industry at Grangemouth in the Forth Estuary (eg Rogers *et al.*, 1989). The high levels in crab may again reflect an inability of this species to metabolise organochlorine contaminants. Surprisingly, HCB concentrations in *Nephrops* were some 10 times lower than those in crab from the same area in the Moray Firth.

Lindane

Lindane or gamma-hexachlorocyclohexane (G-HCH) is less hydrophobic than the compounds previously discussed and has a lesser tendency to bio-accumulate. Concentrations in biota were correspondingly low and limited in range. In the majority of samples of fish and shellfish, concentrations fell in the range of 4 to 44 µg/kg lipid. The exception was *Nephrops* muscle from the Firth of Clyde with a concentration of 500 µg/kg lipid. The Clyde appeared most contaminated by lindane with the maximum concentration in flatfish of 44 µg/kg lipid present in plaice liver.

Small-Scale Studies

The Piper Alpha area

The release of CBs during the destruction of Piper Alpha resulted in elevation of sediment CB concentrations at sampling points up to 20 km from the site (Wells *et al.*, 1989). To explore more fully the effect of this sediment CB burden on fish, samples were obtained at several positions up to 60 km from the wreck in June 1989, one year after the incident. The relative concentrations in the livers of cod, whiting and haddock are shown in Figure 8. Highest concentrations were present in cod and haddock at the sampling site closest to the wreck, some 9 km north. Gradients of concentration were present both to the north-east and south. Levels in whiting were more variable. The three species examined are relatively mobile and will tend to integrate differing sediment CB concentrations over the area. The existence of a strong "signal" despite this averaging effect suggests that the sediment burden of CBs around the wreck of Piper Alpha may be causing limited elevation of CB concentrations in biota.

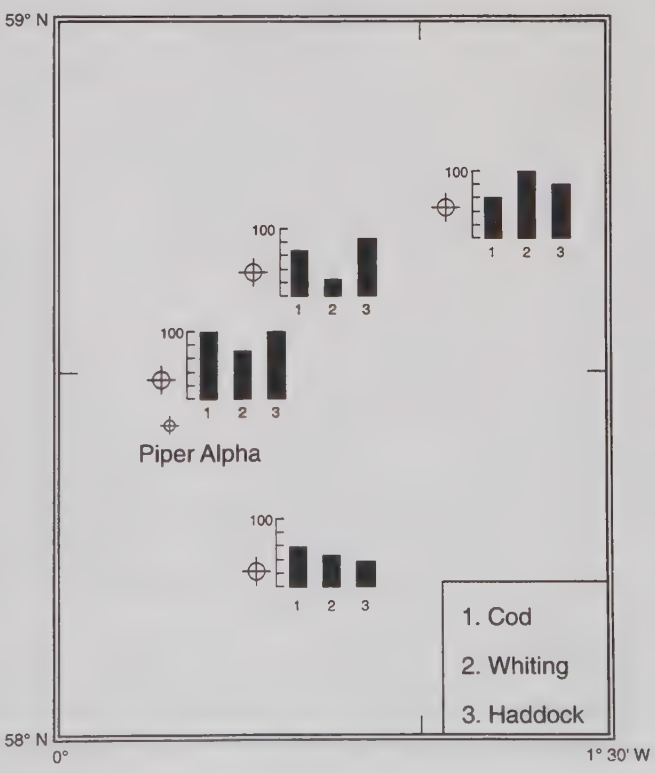

Figure 8.
Relative concentration of chlorobiphenyls in fish sampled in the vicinity of the site of Piper Alpha. Data were normalised to tissue lipid content.

The Firth of Clyde

The Firth of Clyde serves a greater population than any other Scottish coastal water area. Input of domestic and industrial effluent and industrial waste is correspondingly large. The Firth was highlighted by the 1977 "Mussel-Watch" survey of Scottish waters (Cowan, 1981), with levels of dieldrin, CBs, DDTs and lindane in *Mytilus edulis* falling within the upper decile of values found. Further surveys in 1981 and 1982 confirmed sites in the Firth as possessing elevated concentrations of dieldrin, DDT and CBs in *Mytilus*, but indicated a downwards trend in concentrations concomitant with decreasing inputs (Haig and Miller, 1984). Recently, levels of CBs, DDT and dieldrin in cod and herring from the Firth of Clyde were shown to be significantly higher than in fish from other Scottish waters (Kelly and Campbell, 1994).

The relative concentrations of CBs, chlordanes,

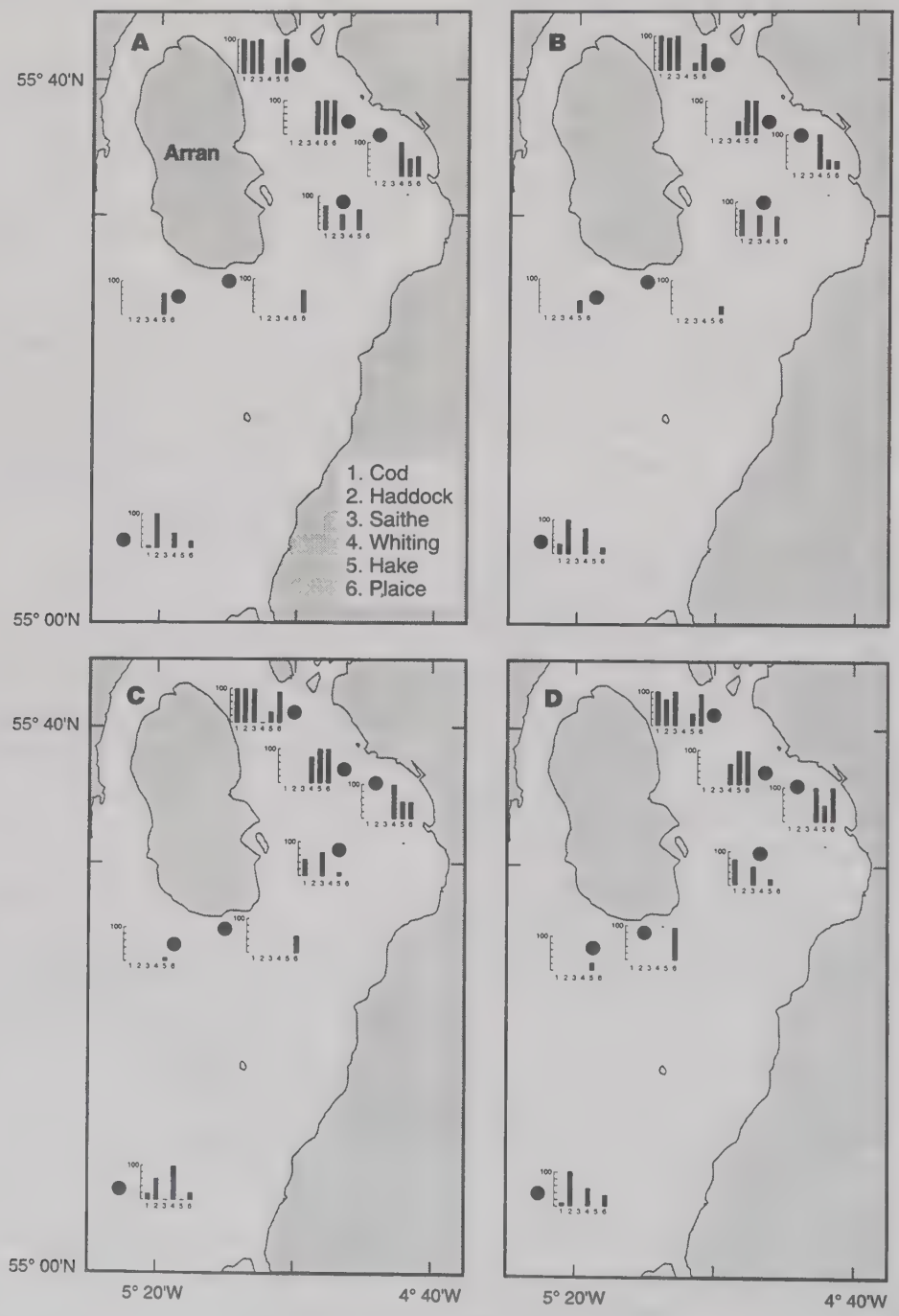

Figure 9.

Relative concentration of organochlorine contaminants in fish from the Firth of Clyde. Data were normalised to tissue lipid content: A)chlorobiphenyls as an Arochlor 1254 equivalent; B) total chlordanes; C)dieldrin; D) sum of 4,4´-DDT,DDD and DDE.

dieldrin and DDT compounds for several roundfish and one flatfish species sampled at seven sites in the Firth are shown in Figure 9. The results suggest that a concentration gradient of organochlorine contaminants was present in certain fish species from the Firth of Clyde. Haddock and whiting showed the smallest differences between sites, whilst cod and plaice showed the largest, reaching a maximum of a factor of 17 for CBs in cod liver. Highest concentrations were generally in the north of the Firth at the Garroch Head, Ardrossan Bay and Irvine Bay sites, and lowest at the North Channel site. The interspecies distinctions are due to differences in habitat, diet, and rate of elimination of contaminants (Lee, 1992). A further major factor governing the distribution of contaminants in fish in the Clyde will be the mobility of the fish. The major inputs of pollutants occur in the north of the Firth through discharge from the Clyde Estuary, industrial and sewage discharge and disposal of sewage sludge (Kelly and Campbell, unpublished observations). Therefore, sedentary fish such as plaice, residing permanently in this area, will accumulate higher contaminant concentrations than more wide ranging fish.

Conclusions

This survey of organochlorine contaminants in fish and shellfish from Scottish waters confirms the influence of terrestrial inputs on marine contaminant concentrations. Highest concentrations were generally present in coastal waters associated with urban and industrial development. Three areas were identified in which contaminant concentrations were higher than the generally low values present elsewhere. These are the Firths of Clyde and Forth and the area of the North Sea in the vicinity of the site of Piper Alpha. None of these areas stood out as being heavily polluted in a European context, ie no sample contained a CB concentration falling into the "upper" category of contamination as proposed by JMG. The Firth of Clyde was the area most contaminated by CBs, DDT compounds, lindane and dieldrin. This may result from a combination of the largest contaminant input and lowest flushing rate of the three. The bulk of anthropogenic input to the Firth of Clyde occurs in the northern section and this was reflected in a concentration gradient of contaminants in certain fish from north to south. The concentrations of CBs, DDT and its metabolites, and dieldrin in Clyde cod and whiting were comparable to those found in fish from polluted northern European waters such as the Dutch Wadden Sea, the German Bight and the Baltic (Haahti and Perttilä, 1988; Huschenbeth, 1986; ICES, 1991; Nicholson *et al.*, 1991), and were less than, or comparable with, the highest concentrations found in coastal waters off England and Wales (MAFF, 1990). Contaminant levels in Clyde herring were less than those reported for the Wadden Sea but comparable with levels in herring from the southern Baltic (Huschenbeth, 1985; Roots and Aps, 1992). The highest concentrations of dieldrin in flatfish and hexachlorobenzene were present in the Firth of Forth. These values exceed both recent measurements in the Baltic and concentrations found in coastal waters off England and Wales, indicating a significant input of these compounds to the Forth Estuary. Concentrations of CBs around the site of Piper Alpha were elevated above those found at other sites in the northern North Sea, and appears to be connected with an input during the Piper Alpha incident.

The higher concentrations of contaminants found in biota in these localised areas affect only a very small proportion of the total Scottish catch. The bulk of demersal and pelagic fish landed in Scotland are caught in offshore areas; for example, of the annual catch of cod in 1990, only 1.2% originated in the Firth of Clyde, 1.0% in the Firth of Forth and 1.5% in the Moray Firth. In fish from the major Scottish fishing grounds of the North Sea, Orkney and Shetland and western Scotland, the concentrations of organochlorine contaminants were generally very low, and reflect "background" inputs such as that from the atmosphere. The major Scottish shellfisheries are in the Minches, the Moray Firth and the Firths of Clyde and Forth. Whilst contaminant concentrations in shellfish from the Minches and the Moray Firth were very low, some elevated concentrations were present in shellfish from the Firths of Clyde and Forth.

The mean values of all contaminants in fish liver were equal to or below the maximum residue limits (MRLs) specified for meat fat, and the "expected" values in fish liver (Food and Agriculture Organisation/World Health Organisation, 1987) utilised as guidance values in the United Kingdom, and are also below the strictest European guidelines for fish liver. All contaminant concentrations in fish and shellfish muscle were less than the strictest European guidelines regarding possible hazards to human health.

References

Cowan, A.A. 1981. Organochlorine compounds in mussels from Scottish coastal waters. *Environmental Pollution, Series B, Chemical and Physical*, **2**, 129–143.

Duinker, J.C. and Boon, J.P. 1986. PCB congeners in the marine environment, a review. *Bjorseth, A. and Angeletti, G., eds. Organic Micropollutants in the Aquatic Environment.* Reidel, Dordrecht, pp.187–205.

Duursma, E.K., Nieuwenhuize, J., van Liere, J.M. and Hillebrand, M.T.J. 1986. Partitioning of organochlorines between water, particulate matter and some organisms in estuarine and marine systems of the Netherlands. *Netherlands Journal of Sea Research*, **20**, 239–251.

Food and Agriculture Organisation/World Health Organisation. 1987. Codex Alimentarius Commission. Recommendations concerning pesticide residues. Part 2. Maximum limits for pesticides residues. FAO, Rome, pag.var.

Haahti, H. and Perttilä, M. 1988. Levels and trends of organochlorines in cod and herring in the northern Baltic. *Marine Pollution Bulletin*, **19**, 29–32.

Haig, A.J.N. and Miller, B.S. 1984. Chemistry of the Firth of Clyde. *Analytical Proceedings*, **21**, 116–118.

Halcrow, W., Mackay, D.W. and Bogan, J. 1974. PCB levels in Clyde marine sediments and fauna. *Marine Pollution Bulletin*, **5**, 134–136.

Huschenbeth, E. 1985. Zur Speicherung von chlorierten Kohlenwasserstoffen in Watternmeer bewohnenden Tierarten. *Archiv für Fischereiwissenschaft*, **35**, 197–204.

Huschenbeth, E. 1986. Zur Kontamination von Fischen der Nord-und Ostsee sowie der Unterelbe mit Organochlorpestiziden und polychlorierten Biphenylen. *Archiv für Fischereiwissenschaft*, **36**, 269–286.

ICES. 1991. Statistical analysis of the ICES Cooperative Monitoring Programme data on contaminants in fish liver tissue and *Mytilus edulis* (1978–1988) for the determination of temporal trends. *ICES Cooperative Research Report*, No 176, 189pp.

JMG. 1990. Monitoring manual of the Oslo and Paris Commissions, OSPARCOM 9/11/1, Annex 5.

JMG. 1992. A compilation of standards and guidance values for contaminants in fish, crustaceans, and molluscs for the assessment of possible hazards to human health. JMG 17/3/10-E.

Kawano, K., Inoue, T., Wada, T., Hidako, H. and Tatsukawa, R. 1988. Bioconcentration and residue patterns of chlordane compounds in marine animals: invertebrates, fish, mammals and seabirds. *Environmental Science and Technology*, **22**, 792–797.

Kelly, A.G. and Campbell, L.A. 1994. Organochlorine contaminants in liver of cod (*Gadus morhua*) and muscle of herring (*Clupea harengus*) from Scottish waters. *Marine Pollution Bulletin*, **28**, 103–108.

Kelly, A.G., Wells, D.E. and Fryer, R.J. 1994. Sampling strategy to detect a change in concentration of trace organic contaminants in marine sediment. *Science of the Total Environment*, **144**, 217–230.

Kramer, W., Buchert, H., Reyter, U., Biscoito, M., Maul, D.G., Le Grand, G. and Ballschmitter, K. 1984. Global baseline pollution studies – IX. c6-c14 organochlorine compounds in surface water and deep-sea fish from the eastern North Atlantic. *Chemosphere*, **13**, 1255–1267.

Lee, H. 1992. Models, muddles and mud: predicting bioaccumulation of sediment-associated pollutants. *Burton, G.A., ed. Sediment Toxicity Assessment.* Boca Raton, Florida, Lewis Publishers, pp.267–293.

MAFF. 1990. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment. Aquatic Environment Monitoring Report No. 22, MAFF.

Nicholson, M.D., Green, N.W. and Wilson, S.J. 1991. Regression models for assessing trends in cadmium and PCBs in cod livers from the Oslofjord. *Marine Pollution Bulletin*, **22**, 77–81.

Rogers, H.R., Crathorne, B. and Leatherland, T.M. 1989. Occurrence of chlorobenzene isomers in the water column of a UK estuary. *Marine Pollution Bulletin*, **20**, 276–281.

Roots, O. and Aps, R. 1992. Polychlorinated biphenyls and organochlorine pesticides in the Baltic herring and sprat. *ICES Paper* CM 1992/E:37.

SOAFD. 1993. Marine Laboratory, Aberdeen, Annual Review, 1990–1991. Marine Laboratory, PO Box 101, Aberdeen.

Wells, D.E., Cowan, A.A. and Christie, A.E.G. 1985. Separation of organochlorine residues by adsorption chromatography prior to capillary gas chromatography. *Journal of Chromatography*, **20**, 556–560.

Wells, D.E., Kelly, A., Finlayson, D.M., Eaton, S., Robson, J. and Campbell, L. 1989. Report on the survey for PCB contamination following the Piper Alpha incident. SOAFD Internal Report, 15pp.

Zoro, J.A., Hunter, J.M., Eglinton, G. and Ware, G.C. 1974. Degradation of p,p´-DDT in reducing environments. *Nature*, **247**, 235–237.

Appendix

Characteristics of Organochlorine Determinands

Lindane

The common name "lindane" (G-HCH) applies to grades of hexachlorobenzene containing >99% of the "c" isomer. Technical grades also contain the "a" and "b" isomers. Lindane is widely used as an insecticide on food crops, in forestry and to treat industrial and household pests. The status of lindane is presently being reviewed. Lindane is one of the more soluble organochlorine pesticides (2 to 12 mg/l) and does not tend to accumulate in either biota or sediment.

Dieldrin

Dieldrin is a non-systemic insecticide used to control tropical insect pests and as a mothproofing agent, timber preservative and termite proofing agent for plastic and wood building materials. Dieldrin and the related compounds endrin and aldrin have been banned in the UK since 1989.

Hexachlorobenzene

Hexachlorobenzene is a selective fungicide used on food crops, as a seed dressing and as a wood preservative. It also arises as a result of waste incineration and as a by-product of several industrial processes.

DDT

DDT is the common name given to a mixture of the predominant 4,4´ and minor 2,4´ isomers. DDT was originally used in agriculture and pest control, but with recognition of its persistence and ability to bio-accumulate its use ceased in most developed countries in the 1970s. Despite this, it still occurs widely in the environment. In general, environmental levels of the parent compound are less than those of the metabolites. The metabolite 4,4´-DDD formed by reduction of 4,4´-DDT (eg Zoro *et al.*, 1974) generally predominates in marine sediment. The product of metabolic oxidation of 4,4´-DDT, namely 4,4´-DDE, predominates in biota. High levels of this compound are indicative of an "old" input of DDT, which has "cycled" through the environment. The metabolites are considered somewhat less toxic to aquatic life than the parent compound.

Polychlorobiphenyls

Polychlorobiphenyls (CBs) are a family of 209 congeners consisting of a biphenyl ring with 1 to 10 chlorine substituents. Commercial products such as "Arochlors", "Clophens" and "Kanechlors" contain varying amounts of chlorine, eg Arochlor 1240 contains 40% chlorine whilst Arochlor 1260 contains 60% chlorine. These products have been used widely in transformers and capacitors for their ability to withstand high temperatures. Other uses are as stabilisers in plastic emulsion and anti-fouling paints and as a component in carbonless copying paper. As with DDT, CBs are persistent and bio-accumulating and therefore potentially harmful to the environment. In recognition of this fact their use in most countries was limited to closed systems in the 1970s. Despite this action, large amounts of CBs have been released to the environment. Owing to the very low water solubility of these materials they tend to associate with particulate material and accumulate in marine sediment. The 18 chorobiphenyl congeners quantified in this work were IUPAC Nos 28, 52, 44, 70, 52, 101, 149, 118, 105, 114, 153, 138, 158, 128, 156, 180, 170 and 194. To enable the present analyses to be compared with previous data quoted in terms of a total Arochlor, an Arochlor equivalent was calculated by multiplying by 2.5 the sum of the seven congeners Nos 28, 52, 101, 118, 138, 153 and 180.

Chlordanes

Chlordane is a broad spectrum agricultural, structural and garden pesticide widely used for treatment of amenity grasslands. Its use has decreased in the light of growing concerns about environmental persistence and toxic effects. Technical chlordane consists of a mixture of 26 or more components. In this study the major components, ie cis-chlordane, trans-chlordane, cis-chlordene, trans-chlordene, trans-nonachlor, heptachlor, and their commonly occurring metabolites oxychlordane and heptachlor epoxide, were determined. The distribution of these components appears to reflect differing environmental stabilities. Cis-chlordane is regarded as the more environmentally stable chlordane isomer, with trans/cis ratios of 1:3 in biota (Kramer *et al.*, 1984; Kawano *et al.*, 1988).

No.30 The United Kingdom Fishery for the Deep Water Shrimp *Pandalus borealis* in the North Sea.
By F.G. Howard, 16pp.

1984 No.31 A Selected Review of Hydrodynamic Force Coefficient Data on Stranded Wires Used in Fishing Gear.
By R.S.T. Ferro and E.H. Hou, 20pp.

1985 No.32 Small Mesh Cod-end Covers.
By P.A.M. Stewart and J.H.B. Robertson, 11pp.

No.33 Attachments to Cod-ends.
By P.A.M. Stewart and J.H.B. Robertson, 15pp.

No.34 The Behaviour of the Norway Lobster, *Nephrops norvegicus* (L.), During Trawling.
By J. Main and G.I. Sangster, 23pp.

No.35 Experiments on the Cultivation of Oysters in Scotland.
By J. Drinkwater and T.R.W. Howell, 20pp.

1986 No.36 Radio-Tracking Observations on Atlantic Salmon Ascending the Aberdeenshire Dee.
By A.D. Hawkins and G.W. Smith, 24pp.

1987 No.37 A Model to Assess the Effect of Predation by Sawbill Ducks on the Salmon Stock of the River North Esk.
By W.M. Shearer, R.M. Cook, D.A. Dunkley, J.C. MacLean and R.G.J. Shelton, 12pp.

1988 No.38 The Intertidal Fauna of Sandy Beaches - A Survey of the East Scottish Coast.
By A. Eleftheriou and M.R. Robertson, 52pp.

No.39 Mesh Selection Within the Cod-end of Trawls. The Effects of Narrowing the Cod-end and Shortening the Extension.
By J.H.B Robertson and R.S.T. Ferro, 11pp.

1989 No.40 The Movements and Spawning Behaviour of Adult Salmon in the Girnock Burn, a Tributary of the Aberdeenshire Dee, 1986.
By J. Webb and A.D. Hawkins, 42pp.

No.41 The Movements of Adult Salmon within the River Spey.
By R. Laughton, 19pp.

No.42 Genetic Protein Variation in Farmed Atlantic Salmon in Scotland: Comparison of Farmed Strains with their Wild Source Populations.
By A.F. Youngson, S.A.M. Martin, W.C. Jordan and E. Verspoor, 12pp.

No.43 Length/Weight Relationships for 88 Species of Fish Encountered in the North East Atlantic.
By K.A.Coull, A.S. Jermyn, A.W. Newton, G.I. Henderson and W.B. Hall, 81pp.

No.44 The Movements of Adult Atlantic Salmon in the River Tay.
By J. Webb, 32pp.

No.45 Records of Porbeagles Landed in Scotland, with Observations on the Biology, Distribution and Exploitation of the Species.
By J.A. Gauld, 15pp.

1990 No.46 An Assessment of the Scale Damage to and Survival Rates of Young Gadoid Fish Escaping from the Cod-end of a Demersal Trawl.
By J. Main and G.I. Sangster, 28pp.

No.47 Force Coefficients for Stranded and Smooth Cables.
By R.S.T. Ferro, 10pp.

No.48 The Behaviour of Adult Atlantic Salmon Ascending the Rivers Tay and Tummel to Pitlochry Dam.
By John Webb, 27pp.

No.49 The Design and Testing of a Divided Trawl for Comparative Fishing Experiments.
By J.H.B. Robertson, A.M. Shanks and R.J. Kynoch,13pp.

1991 No.50 The Movements of Adult Atlantic Salmon (*Salmo salar* L.) in the River Spey as Determined by Radio Telemetry During 1988 and 1989.
By R. Laughton, 35pp.

1992 No.51 The Distribution and Growth of Juvenile Salmon and Trout in the Major Tributaries of the River Dee Catchment (Grampian Region).
By P.E. Shackley and M.J. Donaghy, 19pp.

No.52 The Behaviour of Adult Salmon (*Salmo salar* L.) in the River Tay as Determined by Radio Telemetry.
By J. Webb, 19pp.

No.53 Fish Populations and Invertebrates in Some Headwaters of the Rivers Dee and Spey, 1983-1985.
By B.R.S. Morrison and R. Harriman, 19pp.

Available from:

The Librarian
The Scottish Office Agriculture and Fisheries Department
Marine Laboratory
PO Box 101
Victoria Road
Torry, Aberdeen AB9 8DB